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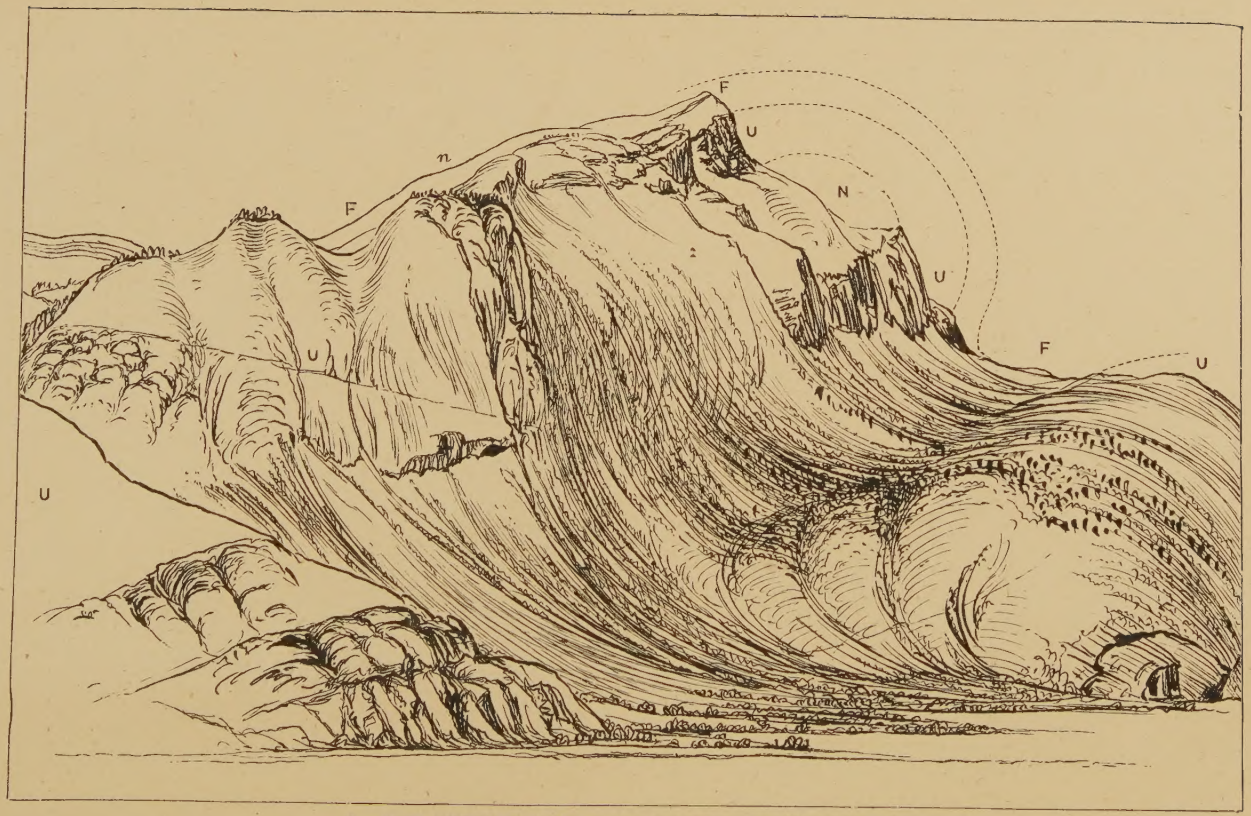
A STUDY IN PHYSICAL GEOLOGY.



I.—THE BRESON, FROM THE VALLEY OF BONNEVILLE.

DEUCALION.—FIRST SUPPLEMENT.

THE

LIMESTONE ALPS OF SAVOY;

A STUDY IN PHYSICAL GEOLOGY.

BY

W. GERSHOM COLLINGWOOD,

M.A., OXON.

WITH AN INTRODUCTION BY

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INTRODUCTION.

THE following book is the fulfilment, by one of the best and dearest of those Oxford pupils to whom I have referred in the close of my lectures given in Oxford this year, of a task which I set myself many and many a year ago, and had been obliged, by the infirmities of age, with deep regret to abandon. The regret is ended now, for the work is here done in a completeness which, among my mixed objects of study, it could never have received at my hands.

The subject of the sculpture of mountains into the forms of perpetual beauty which they miraculously receive from God, was first taken up by me in the fourth volume of 'Modern Painters;' and the elementary principles of it, there stated, form the most valuable and least faultful part

of the book. They had never been before expressed, or even thought of, for the simple reason that no professed geologists could draw a mountain, nor therefore *see* the essential points of its form. So that at this very time being, the large model of the valley of Chamouni exhibited in the library of the British Museum, is a disgrace not only to the Museum first, and the Geological Society next, but actually it is a libel on the ordinary intelligence of human nature. For if people resolutely refuse to look at things in the right way, the law of their nature is, they come to look at it exactly in the wrong.

The only member of the Geological Society, since its energies were diverted to palæontology, who could draw a mountain in outline, was James Forbes, and even *he* could not draw in light and shade; but his outlines were precise and lovely. And it was the accuracy of observation directed by this practice that enabled him to recognize the lines of flux in glaciers, which no previous (nor subsequent, for that matter) geologist had so much as a glimpse of;—

to this day most of them remaining as incapable of tracing the linear indices of motion of glacier waves as the puces-de-glace that live in them.

After comparing notes with James Forbes at the village inn of the Simplon, (see 'Deucalion,' chap. x.), in 1849, I went up to the Bell Alp, then totally unknown, and drew the panorama of the Alps, from the Fletsch Horn to the Matterhorn, which is now preserved in the Sheffield Museum. Then, going up to Zermatt I took the first photograph* of the Matterhorn (and, I believe, the first photograph of any Alp whatever) that had then been made. On the work done in Zermatt at that time, the mountain section of 'Modern Painters' was principally based; but in 1861 I went into Savoy, and spent two winters on the south slope of the Mont Salève, in order to study the secondary ranges of the Alps, and their relation to the Jura. I quickly saw that the elements of the question were all gathered in the formation of the mountains round the Lake of Annecy: and, at Talloires, in the spring

* Properly daguerreotype—photography then being unknown.

of 1862, made a series of studies of them, which only showed me how much more study I wanted.

Being called to England, I left the light blue lake with resolution of swift return; and the time of Troy-siege passed by, before I stood again upon its brink among the vineyards.

In the meantime I had been able to do some collateral work that was of use. The autumn and half winter, till Christmas, of 1862, were spent at Lucerne and Altorf, in examining the relations of the limestone of Uri with the Northern Nagelfluh and Molasse. The summer of 1866, though principally given to 'Proserpina,' yet allowed me time, at Brientz and Interlachen, to trace the lines of Studer's sections across the great lake-furrow of central Switzerland. I learned enough geological German to translate for myself the parts of his volumes which relate to the Northern Alps, and wrote them out carefully, with brilliantly illuminated enlargements of his tiny woodcuts, proposing the immediate presentation of the otherwise somewhat dull book to the British public in this decorated form.

A letter, bringing me bad news, interrupted me one bleak wintry day; and the since untouched manuscript, with its last drawing only half coloured, remains on the library-shelf behind me, like an inoffensive ghost.

It chanced, or rather mischanced, also, that having written 'Unto this Last,' in the valley of Chamouni in 1860, and 'Munera Pulveris' at Mornex in 1861, I was eager at Lake Lucerne in 1862 to translate into pithy English the two first books of Livy,—a design which broke down like that for Mr. Studer, after I had lost a whole lovely day of clear frost at Altorf in cataloguing the forces of the preposition ob, as a prefix to verbs. In the course of these desultory efforts, however, I ascertained that the essential facts of Alpine construction remained to be detailed: that Studer had given only superficial examination to a far too widely extended surface; and while he had spent years of unremitting labour in partially determining the conditions of form in the Jura, the Apennines, and the entire length of the Alpine chain

between Savoy and the Tyrol, had never given the exhaustive attention to any single valley, which was needed to ascertain the scope and results of the metamorphic, as distinguished from mechanical, changes of feature in its secondary strata.

I took up this subject with renewed eagerness in the first leisure given by retirement from my Oxford Professorship in 1879, and received from time to time the kindest assistance and coadjutorship from Mr. Clifton Ward, whose lamented death in 1881 deprived modern science of one of her most patient, powerful, and candid observers; and left me again discouraged, and at pause, in the presence of questions which had become by his help more definite, but in that very distinctness, less assailable.

Feeling also that my strength would no more permit me the climbing of Swiss hills, I resigned hope of doing more among the precipices of the Buet or the Jungfrau; and began, as better suited to my years, the unadventurous rambles by the streams of Yewdale, whose first results

were given in my Kendal lecture ('Deucalion,' chap. xii.)

But here again I soon was in need of help. Though still able easily enough to get to the top of Wetherlam or Silver How, on occasion, I had no time for such survey of the country in all the lights of evening and morning as I felt to be necessary for the understanding of its essential forms: and I entreated Mr. Collingwood, who had before been at work for me on the bed of the retreating Glacier des Bossons, to come to my assistance at Coniston, and make me a perfect model of the mountain group which was within the day's walk of Brantwood.

He gave a summer to this task; and completed his model to a scale of six inches to the mile,—the best, I am bold to say, yet made of any part of the Lake district. But, before we had settled the colouring of it, the usual malignity of my fairy godmother (or gnome godfather) interfered; and Mr. Collingwood had to leave his whole summer's work—like my former ones, re infecta; and to come with me to Italy, more

in the capacity of physician than geologist. His watchful care of me had such good results that before recrossing the Alps, I had formed the hope of returning to my duties in Oxford; and in a newly active frame of mind, asked my friend, while yet the snows were high, to review with me some of the old problems in the much loved recesses of the Dorons and Tournette.

To my (somewhat unreasonable) surprise I found his instinct for the lines expressing the action of the beds far more detective than my own; and felicitous beyond my hopes, in that he was fettered by no scientific theory, and saw the most wonderful group of mountains in Europe with entire freshness of mind and eye.

But he had another advantage over me, in his glance over strata, which I was not prepared for, and which not a little provoked, while it mightily assisted me. All through France and Italy, where we had been drawing Gothic sculpture, Mr. Collingwood, trained in recent science of anatomical draughtsmanship, had been putting me continually in a passion by looking for insertions

of this and the other tendon and gut, instead of the general effect of his figure; but when we got to the hills, I saw that this habit of looking for the insertion of tendon and gut was of extreme value in its way, and often enabled him to see the real direction of original movement in the mountain mass, where *I* saw only the effects of time and weather on the superinduced cleavages, often opposed altogether to, and always entirely independent of, the lines indicating primary motion. On the other hand, as I read over the sheets now ready for the press, I find he has not at all dwelt on one of the questions respecting this motion itself, which I thought to have indicated to him as one of the most needful subjects of inquiry, namely, the relation to it of joints, as distinguished from cleavage.

True cleavage never pays the smallest attention to the fluctuation, involution, or any other caprice of the several strata; but assuredly in any substance not fluid, nor elastic, nor capable of easy molecular adjustment, fluctuation cannot take place without fissures; and I greatly marvel

to see my enthusiastic friend shaking his mountains up and down as a terrier shakes a rat, or a rug,* without ever telling us in what state of cohesion their substance must have been at the time of the operation, or seeming to remember that though one can wave a flag, or wreathe hot iron, one can't wrinkle a deal board, or pucker a *baked* pie-crust. It did not, of course, enter into the design of this volume to touch on the structural phenomena of metamorphism or any others connected with the baking of the earth's crust ;† and it is wise in the author, on the whole, to have restricted himself absolutely to the description of existing forms, and the abolition of recklessly adopted explanations of them by glacial or pluvial agency. But I regret that in his enumeration of component rocks, he should have taken notice only of the changes in one of them, the Lias, where it approaches the Central Alps; and tell

* "Or switching them about like a whiplash into loops and curls," p. 63.

† Geologists seem satisfied, nowadays, that the whole globe is a sort of flying haggis, or lava pudding, out of which, I see by Mr. Ball's lecture on the Corridors of Time, the Moon got pinched at the baker's.

us nothing about the differences of aspect or structure traceable in others of the formations under the same condition. In reviewing my own experience in this matter, it becomes more and more wonderful to me how little the rocks seem to modify each other at their actual junctions. Gneiss runs into Protogine at Chamouni in tongues and veins, without the slightest loss of its own character or pardonablest proclivities to the Protoginesque; and oolite lies flat upon granite at Avallon, with no apparent discomfort or objection, and without allowing the slightest change in its own shaly and crumbly substance, till within a few feet of the actual junction; while the metamorphism which in other localities affects these, or even more recent formations, appears, as for instance in the crystalline marbles of Tuscany, the result of the equable diffusion of heat and distribution of pressure for myriads of years through the entire mass of the substance under modification.

I might have easily prevented the appearance of neglecting these and some other connected difficulties, had I thought it right to interfere in

any way with the natural impulse of the author's thoughts. But I was, on the contrary, so anxious not to disturb—and above all not to check—the direct energy which was doing such good work in its chosen field, that I not only refrained, in looking over the manuscript, from making any suggestions, except in matters of mere arrangement; but took great pains when we were at Geneva to prevent Mr. Collingwood from getting hold of Professor Favre's elaborate analysis of the same district. This I did for two reasons; the first, that I greatly feared Mr. Collingwood might give up the whole design, if he saw to what precision and extent Professor Favre's study of Savoy had been carried out; in the second place, I was extremely desirous to see how far the conclusions of Professor Favre would be confirmed by an independent observer.

Accordingly, I assured my friend, when I had got him with his full sketchbook into a quiet corner of the Hotel des Bergues, that if only he would go on preparing his drawings for the wood blocks, I would myself ransack the libraries of

Geneva for whatever geological works could be of the smallest assistance to him. And so I did: but I only gave him those whose assistance to him *was* "of the smallest!"—and locked Professor Favre carefully up in my own portmanteau. The result was absolutely satisfactory, and the corrections of his own views in points of detail which Mr. Collingwood afterwards found necessary on comparing Professor Favre's sections with his own, were easily made and collected in the postscript to the third chapter.

The drawings which I was so eager to see in progress quite deserved my solicitude, being indeed much better than any by which the volume is now illustrated. Made on the spot, or from immediate memory, they were vivid and expressive in the extreme; but, of course, in many points inaccurate or incomplete. The correction and finishing, with continual hesitation as to what could or could not be expressed in wood-engraving, has taken half the life out of the first drawings; and I shall take good care in any future geological expeditions with the author, to lock up his own

drawings in my portmanteau, as well as other people's, and not let him meddle with them afterwards, till I can get them engraved. On the other hand, the extreme fidelity and skill with which Mr. W. Hooper has facsimiled the final states of the sketches, deserve the author's best thanks, and the public's also; for truly, whatever their shortcomings, the figures in this book are quite the most illustrative of mountain form in its wide symmetries that have yet been contributed to the syntax of constructive geology.

I have but a word more—partly in modification, —partly in support,—of the author's remarks on the influence of Rudisten-kalk in the production of hermits. In modification, that the Eremitic character sometimes takes the less recognised form of Rousseau's retirement on St. Peter's Island, or Byron's by the Bosquet de Julie, while St. Bernard of the crusades, himself the product of a French monticule instead of a Swiss mountain, "discoursing of the lake — asked where it was." Something also in this kind may be insinuated for the marshes of Croyland and Citeaux; nevertheless

I am thankful to be able to associate with this pretty opening chapter of my friend's book, my reminiscence of a real live hermit, whom I found in a cave two thousand feet or so above the valley of the Rhone,—alas! now fifty years ago;—and the expression of my reverent sense of the wisdom of his mossy and cressy retirement, (his little garden had flowers in it also,) as compared with the tormented existence of the modern travelling Eremite, in caves which he has paid millions of money to dig, that he may not see the Alps when he gets to them.

To such better sympathy as may yet be found of Benedictine, Carthusian, or Augustine gentleness, in the hearts of pilgrim folk, I commend this book, for their mountain guide among some of the fairest scenes that ever were formed by Earth, or blessed by Heaven.

JOHN RUSKIN.

BRANTWOOD, 10*th January*, 1884.

THE LIMESTONE ALPS OF SAVOY.

PART I.

ASPECTS.

CHAPTER I.

THE ROCKS.

§ 1. THE HOMES OF THE HERMITS.

THERE has been an infinitude of speculation upon the causes which moulded the mountains and hollowed out the valleys. To account for these familiar and yet perplexing mysteries, a multitude of theories have been rashly set up, and roughly upset; involving in the discredit which they have drawn upon themselves even the very observations on which they were based, and throwing into neglect the set of facts which suggested them. The now fashionable theory of the glacial origin of valleys, and especially of lake-basins, is founded upon the assertion of phenomena whose existence, however freely admitted, would not be the whole truth about valley-formation—would be indeed only a very small part of the truth. But the discovery of the ancient extension of glaciers and the examination of their erosive power have

thrust from men's minds all other considerations, to which it will be the object of this work to revert, in describing further facts of mountain-structure and fuller details of valley-formation; with the desire rather to grasp the whole truth of the case as it is, than to support any easy theory or to offer any specious explanation.

In a word, we shall not first ask or answer the question, *Can* a glacier cut out a valley?—a question upon which all have their beliefs or prejudices, and about which the most contrary arguments and distracting experiments are adduced. But steadily limiting this enquiry to one well-defined and typical district of the Alps, let us there simply look and see whether a glacier *did* cut those valleys or no; considering that only a thorough and exhaustive survey of the anatomy of Alpine valleys can find means to answer fully the question of their origin; and a clear notion of their solid scheme and architecture can only be formed part by part—such clear notion being the only one of any value for our purpose. We need ask nothing about the mechanics of glaciers or any of the vexed questions of to-day's scientific gossip; but simply,—What is the shape and structure of these Alps, seen and grasped as a whole, at a bird's-eye

view? With that knowledge we may be able to answer some questions on the origin of their particular forms, and another day pass on to similar enquiries in other districts. This seems a little thing to ask; but complete and connected knowledge of this sort is not readily obtainable; and even when obtainable, not always rightly valued.

Savoy is a country singularly favourable for the commencement of such a study, not only from the simplicity and definiteness of its strata and the boldness of their relief, but from the accumulated interest attaching to the neighbourhood and centring in it. In learning Savoy by heart we are learning much in little; just as from one play of Sophocles we can learn not only Greek, but philology—not only philology, but history and comparative mythology—not only that, but great lessons in poetry, in philosophy, and in the subtler workings of the human mind. So here we have, first, a landscape peculiarly poetical; inexhaustible contrasts of strength and sweetness; a population of primitive peasantry whose natural nobility is yet unspoiled by the spread of town civilization, and whose natural wealth has till now set them above the needs and wants which too often brutalize the poorer classes of

less favoured lands. We find everywhere the tracks, not yet stamped out, of a history great with stirring incidents and world-wide importance; we may trace the connection between human character and the circumstances of its surroundings in nature; the cause of these influences, in the geological structure of formations absent in England, but here strikingly exemplified;—for the secondary limestones of Savoy are as typical of their kind as the old volcanoes of Auvergne, or the dolomites of the Tyrol; and yet the individuality of these does not lessen their value as an easy epitome of all geology. So that both the associations of history and the accidents of nature combine to make Savoy a country well worth studying.

Here we may recall, if we care, Hannibal and the old Allobroges, "tales of forgotten far-off things and battles long ago"; the Alpine dukedoms and their vicissitudes, still witnessed by many a ruined castle on many a craggy height; but above all, the birth or breeding of many religious ideas whose intensity is their only common characteristic, whose clash filled Europe once upon a time, and the echoes have not yet died away; for we are between the Grande Chartreuse, the Waldensian valleys, and Geneva. But chiefly and principally the Alps of Savoy are the homes of the hermits.

It is interesting, though perhaps impertinent, to remark how intimately limestone mountains are connected with the typical development of Christian asceticism. To the limestone caves and coves of Yorkshire we owe the English hermits, of whom Richard Rolle of Hampole was the chief, and whose influence on our own religious history is more real than recognized. And the Savoy limestone mountains were the home of St. Germain of Talloires, St. Bernard of Menthon, and St. Francis of Sales; not to mention the monks of the Grande Chartreuse, and a host of lesser saints whose memory still survives, and whose names remain; as St. Jeoire or Jorioz, St. Ruph or Rodolph, the brother of Germain,—with many who in their age exerted a power of light and leading which the superficial reader of history attributes to kings and warriors. But the kings and warriors were made or unmade by the monks. And the monks were made by the mountains. And the mountains? It is our business to see how these were made. For we do geology a wrong if we think its tale ends where history begins. Wars and rumours of war, revolutions and reformations, they do not make history; the people and their feelings, aspirations, passions, culture, they make history; of which, battles and

sieges, councils and codes, are only as the barometer is to the weather,—merely the indications. And, once again, the people are swayed by the thinkers, and the thinkers by nature—little though they know it; and specially by the sublime in nature; and most vigorously of all by these limestone mountains.

Therefore beside the purely scientific interest attaching to our study of beds and basins, crags and cleavages, we have always, in treading this ground, the human interest proper to these temples of nature,—high places of false deities if you will, but oftener of some living truth elsewhere unrecognized. And if history be rightly read, it is no mean contribution to it to paint its scenes, to explain their influence; to show the shrine where great men have received their inspirations, and great ideas have been conceived; to be doorkeeper in the temple of nature,—for does not the doorkeeper hold perhaps the key of knowledge?

With such a light by the way, the study of the Savoy Alps will become doubly interesting, as we view the architecture of their mountain-masses, their materials, the ground-plan and elevation of them, the laying down of their stone-courses and brickwork, so to speak; and their final building and sculpturing into forms which

have inspired great minds of old, and still inspire the poets and philosophers of our day, not merely with their sublimest images, but with their deepest and their truest ideas.

§ 2. GENERAL FEATURES.

Wall upon slope, slope upon wall; crowned at last with a mural crown of pinnacled crag, on brows smooth-swarded or snowy-white,—such is the character of the Savoy limestones; marked by this combination of cliff and steep, just as Greek architecture is known by its pillared portico, or Gothic by its arch and tracery.

The walls are of limestone, flawless for the most part, though often caverned; and called the "*Urgonian*" formation by French geologists; by the Germans *Rudistenkalk.* The slopes, always evenly at an angle of some 45°, might be taken for grass-grown *débris;* but under the turf or trees everywhere is a finely-cleaved and loose-bedded living limestone—the "*Neocomian,*" from the ancient name for Neuchâtel, where it was first studied.

Below this great crag and great slope lesser repetitions of the same form, like alternate wall and roof in a Chinese pagoda, mark the Jurassic formations; but in this district the Jurassic is so

kept underfoot that it is mostly invisible, and at best only crops out as a mighty base to a mighty building. For example, in the Dent de Nivolet—that mountain with the cross above Chambéry; or on the northern side of the valley of Annecy; or, once more, to the left of the road from Geneva to Cluses, along the valley of Bonneville, at the base of the Môle.

At this roadside, by which every traveller in the Alps has passed, some of the most important geological features are strikingly exhibited. To the right just before Bonneville stands the Montagne de Couz, in which two slopes of Neocomian enclose one wall of Urgonian (see Plate XI.); and next to it the Breson, with two walls of Urgonian enclosing one slope of Neocomian, all flanked by a great cylindrical roll of Urgonian (see Frontispiece)—a feature repeated in Mont Saxonnet, between Bonneville and Cluses, and still more markedly in the mountains of the Reposoir (Mt. Vergy), at the entrance to the defile (see Plate XIII.).

This cylindrical roll, or vaulted arch and waggon-roof, is almost as stupendous a feature of the limestone as its vertical Urgonian cliffs. Like some huge kraken, half emerged among the ice-bergs, this mountain-mass stretches for miles along

the plain, or leans against the precipices,—its back, one unbroken coil of solid stone, thick as the cliffs themselves are high.

As you leave Cluses, the scenery runs wild in an attempt to outdo all commonplaces of the romantic or sublime; but every giant crag, veiled in lace of snow or capped with fleecy cloud, may be known for Urgonian; while the Neocomian underlies each sweeping slope of velvety pine-forest or satin pasturage, dotted with tiny farms and twinkling flocks.

But when neither wall nor slope nor vaulted roof appears, it means that the formation is different from these just described. Little low hills like a choppy channel sea, between great surging Alps and the breaker of the Salève—these betray a modern soil, the *Molasse*. The cones and domes of Chablais, to the left of Bonneville, and again those to the right of Sallenches, mark an earlier —the *Lias*. And when we come to the valley itself of Chamonix, there is something in the character of it which recalls our English Lakeland or Snowdonia, in the thunder-scarred brows of igneous rock and the trail of their scree-skirts, sweeping the valley.

At Sallenches the formation ends in a great ridge, part of that wall of mountain which begins

at the Dent du Midi, and runs through the Buet, the Rochers des Fiz, and Aiguille Varens. The line is broken away there, but caught up to westward by the Dorans, and so on to Chambéry valley. The great wall parallel to the central chain—like the outer brink of some long castle-moat—is one of the most noteworthy features of the Alps; facing inwards, forming one side of the great longitudinal succession of valleys, Trient, Chamonix, Isère. In its stone-courses and cornices the masonry of Savoy can be plainly seen throughout and studied on a large scale in natural section. But broken off there, these limestones hardly appear again until you cross over the hills and far away into Italy.

§ 3. THE FORMATIONS.

Though the preceding section described the aspects essential to an understanding of the general structure of Savoy, it is well to complete our acquaintance with the important features of less notable strata. Palæontology, though of immense value in determining their succession, is by no means needful to the work we have in hand, which will take its results for granted, and forbear to complicate the subject with allusion to its facts.

Above the crystalline rocks of the central Alps and the Anthraciferous formations lie various beds of Triassic age, which hardly appearing in our district need hardly be noted.

Upon these rests the Lias, a dark blue slate, becoming talcose as it approaches the region of more powerful metamorphism, in the central Alps.

Jurassic.

Above the Lias come sturdier stuffs, breaking here and there into precipices of such size and such material as the Jura mountains afford, and called after them *Jurassic.* This stage is made up of several steps, greatly altered from their appearance elsewhere, through the heat and pressure attendant on Alpine upheaval, but still identical with Bath stone, Kelloway, Oxford clay, Coral rag, Portland and Kimmeridge beds. But of these the Oxford only is important.

The Bath stone or oolite—hard, rough, sometimes shaly from local cleavage—contains a sort of flint. It is chiefly seen in the Mt. du Chat between the Lac du Bourget and the Rhone, but not often appearing in our district, need not make much figure in its description.

The Kelloway beds appear only on the bank of the Rhone, beyond the Lac du Bourget, between

Chanaz and Lucey, and then only from one to two yards thick; greyish blue, or stained red with the rust of little iron bullets, of which it is full.

The Oxford formation underlies all this district to the thickness of one hundred to one hundred and fifty mètres, and appears in cliffs wherever the valleys have been cut deep enough to disclose them—that is to say, on the northern wall of each of the three great cross-valleys. At Bonneville to the left it makes a long escarpment, introducing the Môle; similarly it forms the base of the Tournette of Annecy and the Rochers de Lanfon, containing the caves of the hermits, and the wonderful cascades of Talloires; and appears to the left as you pass up the valley of Chambéry, where a fault doubles the section of Oxford stone.

Its lowest beds are a compact grey limestone, about five mètres thick, enclosing little fossil sponges.

Next, a great hard grey layer of one hundred mètres, with very few fossils; but near the top flints of a sort.

Then a bed of gritty dolomite; this, when it forms the surface, cracks up into these grey cold slabs which, half overgrown with flowers and grass, make so many Jura summits resemble a country churchyard.

This Oxford stone is all that appears of Jurassic throughout the most part of Savoy; for the remaining steps—Coral rag, Portland, and Kimmeridge—appear only along the western border of this district, from the Salève to the Lac du Bourget, and occasionally in the Chablais.

Cretaceous; Neocomian.

Above the Oxfordian, except in the sub-Alpine region, is always the Neocomian (a title formerly extended to several beds above it as well). Its general aspects have been described—how it rarely appears as a cliff, for its bricks are so loosely cemented together that a wall of them soon becomes a ruinous heap. It is 240 to 260 mètres thick, in three beds—first a yellow-grey clayish limestone; second, the same, only bluish; third and uppermost, yellow, with green grains and few fossils, These beds are bared sometimes by a river ravine or by a road cut through them, as at Fort l'Ecluse, or the Pont de la Caille, or the Petite Gorge of the Salève, whose summit sketched against the sky in soft curves—different from the springing curves of (for example) the Reposoir—betrays the less solid material. The summit of the Mt. de Couz, near Bonneville, shows a sort of cone of Neocomian; the remnant of a great loop or

fold from which the top stratum of Urgonian has been lost. The Neocomian is often bright red, owing to the iron it contains—as, for example, on the shore of Annecy lake at Duingt.

Urgonian.

Urgonian, the stone of which Savoy builds her boldest architecture, can be recognised from the description already given. It is about 200 mètres thick, and consists of three beds.

The lowest,—thick, chalky, and full of fossils, especially the Rudistes—Radiolites and Caprotinæ (whence the German name Rudistenkalk).

The middle, a narrower bed of yellow or blue, which easily weathers and reddens in the air, forms that horizontal streak generally seen halfway up a great Urgonian precipice.

The upper bed is something like the lower but not so white. The difference in colour is very striking in the same formation in different places. At the Perte du Rhone the Urgonian is milk-white; at Bonneville and Sixt already grey and brown, being altered by the heat attending the upheaval of the Alps, and altered more as it approaches the centre of disturbance. Nor is it only the Urgonian which undergoes this change; for in all the formations a gradual transition can

be traced from an unaltered to a highly metamorphosed condition as you approach Mt. Blanc.

Upper Cretaceous.

Above this comes a series of soft and comparatively unimportant formations, never attaining any great thickness, nor ever forming any interesting feature in the landscape—rather clothing or filling up its crests and cliffs. These are, going upwards, Grit, Gault, Chalk.

Then as *débris* of these rocks, the Eocene, Nummulitic sandstone and Flysch.

Grit.

Grit—called by the French the Aptian—rarely appears in our Savoy Alps; where it does it presents two beds—the lower soft, the upper hard, of yellow or blue marly limestone, full of fossils of much the same character with the Urgonian.

Gault.

Gault (the Albian formation) is always present, though it never forms a summit-surface without some sturdier bed above, to protect it from the weather. Toward the central Alps it is metamorphosed into dark broken beds rich with blackened fossils and green grains of silicate of iron, and separated by gritty shale-bands.

Chalk.

Chalk (or Senonian) is the same formation with that of England and France,—whence, from Sens, it is named. It is altered in the Alps to a hard grey stone, with few fossils, but flints of course, and slightly varying in the succession of its beds. It occurs along the line of the high mountains from the Chartreuse to Chablais, overlying and protecting the Gault; but in lower districts the chalk has never been laid down, and the Gault consequently washed away.

Eocene; Nummulitic Limestone.

Above this, the Eocene formations—firstly, Nummulitic limestone in four aspects.

(*a*) Generally surrounding others, Conglomerate; that is, pebbles and sand cemented with limestone —sometimes, as at Thônes, wanting; or as at the viliage of Breson, behind the mountain of that name or in the valley of Chambéry,—much developed. It contains nummulites and polyps; and chalk flints, which show that the material from which it was made was derived from the ruin of the formations on which it rests.

(*b*) Hard grits containing nummulites, and vary-

ing in colour from white, away from the Alps, to brown near them.

(*c*) Beds of lignite, blackish brown, and fossiliferous.

(*d*) Nummulitic limestone—yellow in the south and blue in the north.

Flysch.

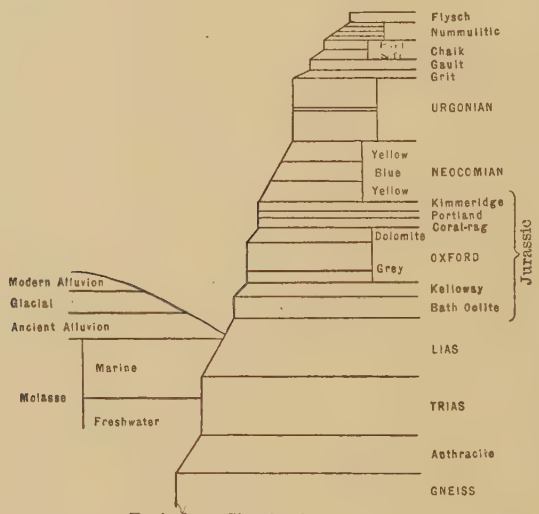
Above this rests the Flysch, or, as it should be called in these Alps, Macigno; a formation of blue shales that rot and redden in the air; full of mica and quartz, which show that it is mere *débris* of the central Alps, with remains of seaweed and fishes; at times running to a great thickness; —indeed, between Bonneville and the Lake of Geneva it is estimated at more than one thousand mètres thick.

Miocene; Molasse.

By partly an accident in the deposition of Flysch, over a small sea-area, and partly the necessity of the deposition of Molasse at the foot of the hills whose *débris* it is, we find Flysch and Molasse mutually exclusive, though resembling one another so much as to be often indistinguishable. The beds of Molasse are sandy, gritty, clayey, marly, pebbly, puddingy, or limey;—the

last, evidently deposited in fresh water; the upper, much less extended, in sea-water, containing fossils to match, and some remains of vegetation turned to occasional seams of coal.

Last of all, and quite unimportant in Alpine structure, are the preglacial and interglacial deposits,



Typical profile of a Savoy Alp.

glacial boulder-clay and moraines, and various alluvia.

From this sketch of the different formations employed—so to speak—in the architecture of these Alps, it will have been seen that while the fossil remains contained in them are of great

importance to mark with elaborated certainty their comparative ages, succession, and extent; yet a knowledge of Palæontology is by no means necessary to a study of the structural geology of Savoy. The beds, whose fractures and folds it will be our especial endeavour to trace, are sufficiently characterised by their general appearance; and their distinctions are readily learnt and easily remembered, perhaps more easily with the help of the scheme or typical section on opposite page. It does not pretend, however, to represent their relative thickness, which varies greatly.

CHAPTER II.

THE RANGES.

§ 1. SOUTHERN DISTRICT (BAUGES).

THE secondary formations of Savoy reach in long ridges from the Lake of Geneva to the Grande Chartreuse; from Mont Blanc and its chain they surge westward, wave upon wave, to end in a huge rolling breaker shattered, as it might seem, upon some long, sunken reef. Over a narrow space of broken lowland another billow sweeps—the sub-Alpine chain of Salève, and then another, the first of the Jura hills; whose ebbing ripples, beyond the Rhone, overflow the plains of France.

Striking as it is when seen as a whole, this wave-like character of the Savoy Alps is by no means singular. There are not many true mountain-systems (as distinguished from mere tracts of down or dune) which do not offer some resemblance to waves; and the fact, popularly noted, has occasionally suggested popular errors. It is hardly

worth while to discuss these; sufficient to note that the precipices of such ridges do not all "look" toward any one point of the compass; sometimes even in a small district they are apparently confused. And so far as they are regular, their configuration has nothing to do with the earth's revolution, as it has been suggested, though perhaps hardly in earnest. Nor even is it always the direct result of the structure of the strata; for there are cases in the English lake-district where the cliffs are not abrupt sections of beds with dip producing the gentler grassy slope behind;—where these smooth "backs" are simply the accumulation of glacial drift upon a rugged spine of broken rock, like the rough brick core of a Chinese colossus or a pillar in a London porch, daubed over with stucco. In the Coniston fells, for instance, the ancient ice-flow seems to have plastered its *débris* on the north-western slopes as with a trowel, or as a child's wooden spade banks up and smoothes down the sand against his fortification of flints and oyster-shells.

These Savoy wave-ridges, however, *are* the direct result of folding and crumpling in the limestone beds, and their precipices the fractured sections of them; for the glaciers, though enormously active in the great ice age, have never swamped

these Alps so utterly as the great northern ice-field swamped our little hills. It was Elie de Beaumont who first remarked how these mountains, and all others similarly flanking the central chain of Alps, are disposed in long parallel lines and nearly continuous ridges,—broken, but not ended, by the valleys which cross them; and separated by troughs whose mean depth is constant. That is to say, the Alps, taken roughly as a whole, are like a long, narrow, ploughed field, whose furrows run in the direction of its length, though here and there cut by transverse drains. The field, even apart from its furrows, is not flat: it is ridged along the middle like a roof, and creeps up and down hill like a path over the moors. At its points of depression, glacial and alluvial soils have filled up the troughs into broad open valleys, or drowned them and the ridges together under one general level of lowland. But the fact of their existence in original continuity can be plainly traced or safely argued, like that of the roads and hedges when the floods are out, up the Thames.

Not only is this regularity masked by disappearance of the furrows and ridges under water or under ground, but it is disturbed by frequent dislocations; which to the spectator on the spot

appear to be indeed "enormous solutions of continuity," though the map shows them to be no more serious in proportion to the great mountain-lines which they switch aside, than are the points of a railway junction; which indeed they most nearly resemble. And a good general grasp, as well as a careful examination of physical and geological features taken together, will afford a clue to the reëstablishment of the normal, original parallelism.

These mountain-lines, like the sea-waves, are in some cases rounded, swelling billows; in others, crested ridges, with one smoothly rising, one steeply falling side; and some even take the shape of toppling breakers, as their internal structure reveals. The precipices of these later sorts do not look all one way; but neither are they quite disorderly. De Saussure, with whom began, and with whom for some time ended, the careful and competent examination of the physical geology of the Alps, remarked that in the eastern ranges precipices look toward the Alps; in the western, toward the Jura. That long wall, the eastern limit of the limestone, running from the Dent du Midi to Montmeillan (on the Isère, just out of the map, south of the Rocher du Guet), faces toward Mont Blanc; the corresponding wall

on the west looks over the Rhone and Jura. In fact, the whole long band of limestone Alps is divided along its length into two narrower bands with opposite physical characteristics; which seems to suggest at first sight that whatever causes created the precipices must have acted inversely on opposite sides of the district,—outward from within, or inward from without. But for the present it is enough to note the fact.

These general remarks upon the parallelism, continuity, and configuration of the ranges apply to similar districts on the flanks of the whole chain of Alps; and certainly to the whole of Savoy, west of Mont Blanc and its gneissitic supporters.

But of this great mountain-tract the most markedly *cretaceous* and strictly Savoisian limestones are limited by the lowlands on whose edge stand Bonneville, Annecy, and Chambéry; the sub-Alpine wave, from the Salève to Aix, being a sort of link between Alps and Jura, showing some of the characteristics of each. And the whole land of Chablais to the north of that great valley of Faucigny, through which runs the road to Chamonix,—all this whirlpool of mountain waves has a character so much its own that it hardly, at first sight, appears to belong to the same

system of parallel lines. Most of its peaks are not cretaceous; and though its continuity with the Alps of Annecy is perfect and easily traceable, yet it undergoes such modifications and transformations as can only be hinted within the compass of this short sketch.

The country, then, with which we have specially to do, consists of those cretaceous peaks from Bonneville and Cluses to Chambéry and Montmeillan, and divides itself easily into a southern and a northern district, on either side of the lake and valley of Annecy.

The sketch map of the whole of Savoy is an attempt to represent the general lie of the land, the parallelism and swerve of the mountain-chains, the bold and well-defined cross-cutting of the valleys; like streets in a town, of which the houses are hills.

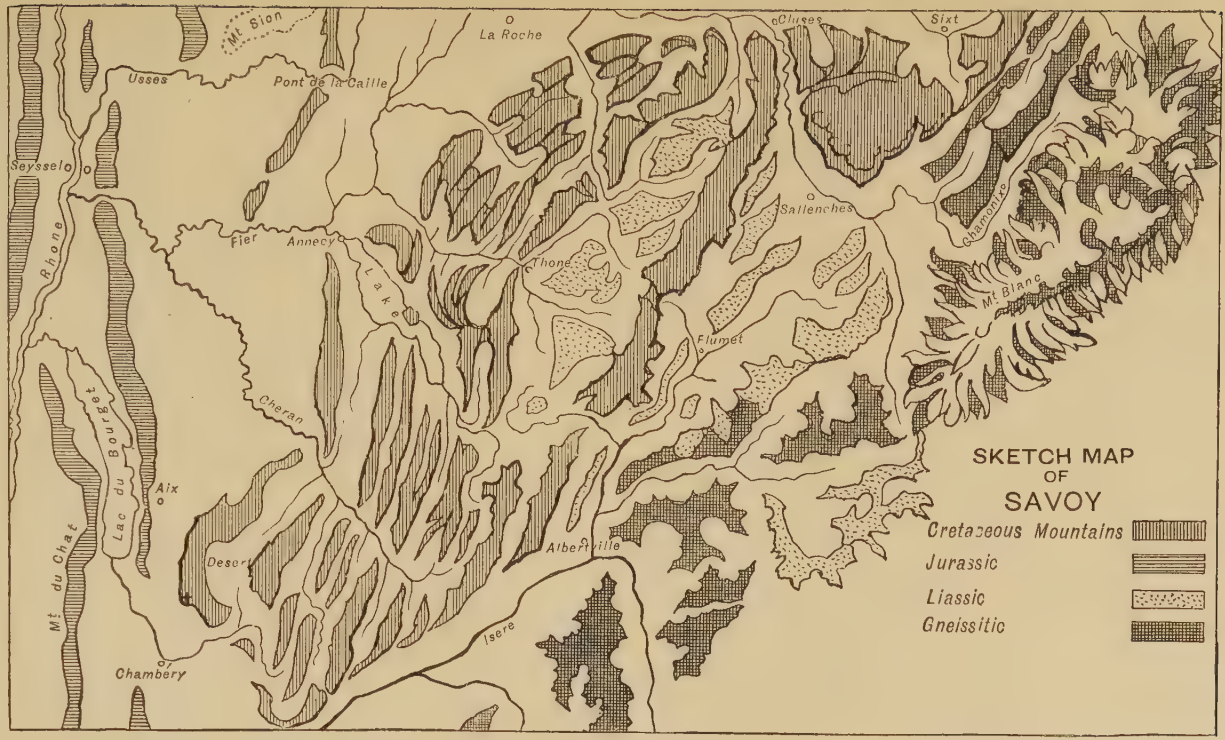
For greater clearness a simplified style of map-drawing has been adopted, which attempts to show every mountain-mass as detached from the valleys and the plain by a single contour-line. This line, however, is not intended to mark off any one general level above the sea; for the whole district rises toward the central Alps so steeply that the western summits would be drowned in any deluge which just washed the feet of the

eastern ranges. Merely to reduce the hypsometrical chart, therefore, would not in the least suffice to show the real mountain-masses. Fortunately for this sketch map, these masses are in most cases neatly distinguished from their surroundings, both physically and geologically; for they rise precipitously, or at least steeply, from level valley bottoms or undulating lowlands, as great rocks out of alluvial soil or molasse-mounds. And so the contour-lines serve to show their steep flanks or sheer faces (the thickening of the line signifying its steepest parts); and also mark the boundaries between the stuff of which the mountains consist and the surrounding soils.

By the shading is roughly shown four main groups of geological formation;—to eastward, the upthrust gneiss and associated granite, mica-schist, and so forth; to westward, the Jurassic beds, by whose outcrop, as summits, Jura is distinguished from Alps; in our district, the characteristic cretaceous rocks, split into two bands, whose opposite physical character has been noted; and intruding between these, lower formations, chiefly Liassic, with here and there a scrap of Trias. Thus the sketch-map, slight as it is, serves both as a physical and geological chart of the country.

As it was specially necessary to keep the masses

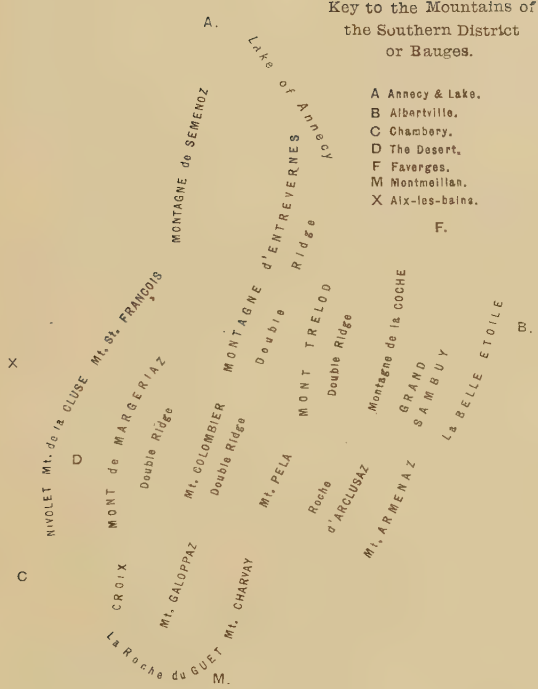
III.*a*.—SKETCH MAP OF SAVOY.



III.6.—SKETCH MAP OF SAVOY.

IV.

Key to the Mountains of the Southern District or Bauges.



V.

Key to the Mountains of the Northern District or Genevois.

A Annecy & Lake.
B Bonneville.
C Cluses.
D Duingt.
E Gorge des Evaux.
F Faverges.
O Thones.
T Talloires.
S Sallenches.

VI.

Key to the Mountains of Chablais.

B Bonneville.
C Cluses.
Ch Chamonix.
M Martigny.
S Sallenches.
S.M. St. Maurice.
T Thonon.
V Villeneuve.
X Sixt.

clear and clean, not much lettering could be introduced. To supply this want, keys are added for each district, in which the names of the mountains will be found to correspond with their contours on the map. Unfortunately there is no generally accepted and easily learnt nomenclature of the Savoy mountains; each little peak and prominence has its own title—or choice of titles; still more complicated by variety of pronunciation and eccentricity of spelling. This map makes no pretence to settle the orthography, but names the masses sometimes from their highest summit, sometimes from the nearest village; attempting, however, to be intelligible and consistent with the descriptive text. And for shortness, the prefix of *Rocher*, *Montagne*, *Point*, or *Dent* has often been dropped; though indeed in some fear of seeming impertinence to these tellurian Titans. It may seem a whimsical notion to those who do not know, or who do not love the things of Nature; but why should not a great mountain be as worthy of respectful approach as a great man? both being masterpieces of an all-creative Power, and owing their only dignity to the divinity that made them what they are.

Before passing on, the imperfections of this map should be noted. For want of mature consideration

and sufficiently diligent revision, several errors have crept in, and much neatness of detail has been omitted. The names of Isère, Chéran, Thônes, have been misspelt; La Roche du Guet, Monts Charvay and Pela should have been shaded horizontally. Several of the mountain-masses have been clubbed together where they might have been more truthfully detached,—as the groups of the Tournette, Breson, Parmelan, Couz, and Varens; Mont Armenaz should have been separate from the Sambuy; and the Nivolet range and the twin crests of the Point d'Arclusaz are drawn unnecessarily straggling. With these corrections made, the text will be found more accurately illustrative.

The first key shows the mountain system of the more southerly of our two districts—that called Bauges (or Beauges), between Annecy and Chambéry. In this diagram the mountains are represented by their names, occupying the space and taking the direction of the actual crests.

The district, but for disturbances which make the north-eastern and south-western ranges take an outward trend, would be rudely rhomboidal; and consists of ridges running roughly parallel to the central Alp-chain and to one another. They are terminated at either end by the great cross-valleys

of Chambéry and Annecy, and divided equally through the middle by that of the Chéran. The two last-named valleys do not simply truncate the rolls or folds of strata which form the mountain lines, but are complete through gentle synclinal troughs, with their deepest dip deepened by a sharp slit groove, and their symmetry spoiled by more or less of a downthrow to the south.

The wave-troughs or bye-valleys are, as the section shows, alternately steeply anticlinal and steeply synclinal; as if crushed laterally together, and quite different in character from the easy lines that dip into the greater cross-valleys.

The parallelism of these ridges, and to some extent their continuity, has been disturbed; as though the sculptor's hand in modelling the whole had pressed first to right and then to left as it passed down the map. And indeed the place and direction of such a force as would produce this shaping is still shown by a band of bared Jurassic beds, which crops out like a wedge from below, thrusting apart and aside the cretaceous strata above it, and dividing the ranges whose precipices look east from those which look west. At the valley of the Chéran it distorts the wave-ridges, so that the northern district lies well to the east of the southern; and while

Nivolet is the undoubted continuation of Semenoz, Entrevernes and Trelod appear, but falsely, to be represented by Colombier and Pela respectively. The identity of the westernmost ranges—which can be traced independently in several respects—gives a clue to the correspondence of the rest, too confusedly shown in the map. It might also seem that the northern ranges of the Belle Etoile, Coche and Sambuy had no definite continuations southward; and that towards the Isère and Montmeillan their place were taken by mere Jurassic mounds in the valley of the Isère, from which the cretaceous superstructure has disappeared.

But as we have seen, the Chéran runs in the line of a great dislocation, which throws the ranges south of it several miles to the westward. Their true correspondence can be disentangled; and the time spent in tracking it out is not wasted if we can establish the truth of Elie de Beaumont's law (p. 24), to the smallest details. When we come to discuss the valleys, and to estimate the effect of glacial action on their formation, the facts now under review will assume a great and perhaps unexpected importance. Beside which, there is a fascination in tracing the neatness and order of similar shapes in waxing or waning series, and in apparently complex though really simple sequence;

and in finding the forces whose resultant action would produce such curious results.

The true correspondence of these ranges of Bauges is as shown in the scheme on p. 34.

The connection of No. 1 we have stated as independently proved. That of No. 2 is justified by a great fault dividing it from No. 1, and by homogeneous geological structure throughout. No. 3 shows the same twin-crest shape on both sides the Chéran, becoming however much more marked in the southern portion. With No. 4 the confusion, so far as there is any, begins. The Montagne de la Coche—by which name is designated (perhaps incorrectly) the whole range between the valleys of St. Ruph and Chevaline—is a single ridge of Jurassic rock ending some distance to north-east of Ecole, the village at the head of the straight valley of the Chéran ; from the south-west of which runs a precisely similar ridge, whose chief summits are Mt. Pela and Mt. Charvay. So far the connection is obvious ; but just at the properly named Mt. de la Coche is a kind of ganglion or knot of ridges, entangling this with No. 5. No. 5, however, has in both cases so marked a twin-crest shape, in contradistinction to the single ridge of No. 4, that there is no real mystery as to the right clue of continuity. And No. 6 is a short, simple

Lake of Annecy.

IV. 1. Semenoz. 2. Entrevernes. 3. Trelod. 4. Coche or St. Ruph (*Wedge.*) 5. Sambuy. 6. Belle Etoile. IV.

III. Semenoz, Entrevernes; Trelod; Arclusaz; 6. Armenaz; III.

R. Chéran.

II. Cluse; Margeriaz. Colombier. Pela. 5. Arclusaz, II.

I. 1. Nivolet; 2. Croix; 3. Galoppaz; 4. Guet, Charvay; (*Wedge.*)

R. Isère I.

Valley of Chambéry.

ridge, broken like the others, but not by the same dislocation ; with Jurassic summit and long fault on the east flank, marking its unity beyond any doubt. In the sketch map, the Belle Etoile is the last cretaceous range next Albertville, ending sharply and steeply to south. Mt. Armenaz is the small mass between the straight Chéran valley ending at Ecole, and the word "Isère" ; unfortunately it has been drawn as part of the same mass with the Grand Sambuy, which disguises its true position with respect to the Belle Etoile range. Part of the twin crest of the Sambuy has also lost its hold upon the main mass ; the Armenaz, its continuation, is represented by two shapes which are both too large and too irregular – oversights which the reader is requested to forgive.

Not only is this district of Bauges broken across by the Chéran, but each of the halves so divided is subdivided ;—the southern by an irregular but traceable dislocation which throws the southernmost border slightly back to the east, leaving two thwart-masses or cross axes of elevation I-I and II-II in the scheme ; and the northern half by a rudimentary crack whose results are rather curious. Semenoz is broken but not dislocated ; Entrevernes is both broken and dislocated ; Trelod is wryed but not broken ; the southern extremity of Coche dis-

appears ; Sambuy is thrown into awkward complications ; and it is at this same crack, not at the Chéran dislocation, that Armenaz is pushed so far to the west of the Belle Etoile ; leaving two cross masses, III-III and IV-IV. As already confessed, the sketch map does not show these details, which can, however, be verified upon any good map of Savoy.

The results of this rather tedious description, simply stated, are as follows. All the cretaceous ridges are present, and almost in their entirety ; though they are dislocated they do not disappear, except at the points where the dislocation seems to be most energetic. The valley of the Isère is not a trough cut obliquely across them ; but merely follows the margin left by the process (whatever it was) which threw the parallel Alp-lines into their present confusion ; and—we may anticipate thus much—at the same time denuded the underlying Jurassic beds here and there of the cretaceous strata. The rhomboidal space of limestone Alps in north-and-south parallel lines is cracked across into four divisions (marked by the Roman numerals) ; as if heaved up from below at four places in such a way as, were the country a plain or tableland—without its colossal wave-ridges—would create four oblong plateaux divided

by deep ravines. And moreover the distortion of the wave-ridges, now to this side, now to that, seems to originate along the line numbered 4, or thereabout ; as though a wedge had been driven in from underneath, had split away the rock above it, and driven to right and left the ranges on either side. The complex result presented is just as if, at four places along that line, wedges had been hammered in between the waves, by some great force from below creating cross-cracks and cross-axes of elevation, and displacing the wave-lines from their original parallel straightness. In the next section we will trace the history of these waves and wedges a little further to the north.

§ 2. THE NORTHERN DISTRICT (GENEVOIS).

The northern of our two districts, the territory of the ancient duchy of Genevois, includes some of the most interesting mountains of Savoy,—indeed of the whole Alps ;—the strangely-folded Breson of Bonneville ; the rugged range of the Reposoir ; the craggy Dorans of Sallenches ; the conical Montagne de Couz, over against la Roche ; the Parmelan and Montagne de Veyrier near Annecy ; and above Talloires, up Annecy lake, the Rochers de Lanfon and the Tournette.

All these different mountains and masses possess

the strongest distinctions of individuality. Many of our English hills may be misnamed when seen at a distance, but these are as unlike one another as men and women are: you recognize them at a glance, seen from any point,—and even in any part, as you tell "*ex pede Herculem.*" And yet they are all of one family; formed by strict laws and simple forces out of similar materials and under similar circumstances; which however admit, or rather necessitate, such little varieties of combination and change of emphasis as make all the difference between one person and any other;—very small, compared with the mass of resemblances; but without which "How should I your true-love know from another one?"

The wave-ridges of the southern district are continued northwards in strict succession; and all their remarkable summits are mere fragments of these long ranks, or highest reaches of arched and aspiring crests. But as at the Chéran we saw how a dislocation threw the whole southern half to westward, so that the wrong continuations, so to speak, were tacked on to the ridges of Entrevernes and Semenoz, so this northern district of Genevois is broken across and across, and the pieces pushed about like chess-pawns.

To begin with, everything north of the valley

and lake of Annecy is pushed to the west,—out of all apparent continuity, like the lines of an army broken by the charge of an enemy's column. But the disturbance is not from without: it is caused by the reappearance of the "wedge" in the midst of our serried rock-ranges. For though the regularity of the western half of the district is much broken, the wall of rock which fences the Savoy secondaries from the valley of the Isère and the central Alps, beginning in the Belle Etoile, runs in unhesitating continuity through Mont Charvin and the Dorans right away to Magland and Cluses.

The "Wedge."

West of this comes the "Wedge," or a series of upthrusting wedges, whose influence, already suspected in the south, now makes itself strongly felt in four masses, which for convenience I roughly name by their principal peaks—Sulens, Venesin, Planay, and les Almes (with Lachat). That this is a real upthrust, and not merely a greater roller of the wave-system, denuded more than others of its superincumbent limestone beds, seems to be shown by the sharpness with which Lias and Trias appear, like a volcanic island in the sea. But whatever be the cause of this unexpected

intrusion, its own structure, quite unlike the regular limestone ridges, and its influences on those to the west and east, show it to have been produced by forces other than those which first crumpled up the whole district into the long wave-lines.

The four summits—Sulens, Venesin, Planay, and les Almes—are not in a straight line; in this respect not unlike the wave-ranges. But a glance at the map and key will show that their irregularity is not dependent on that of their neighbours, but the reverse—the Wedge distorts the waves. Sulens thrusts Mont Charvin to the east, and the Tournette but little to the west. Venesin allows the northern end of Charvin to trend eastward, but thrusts Traversière away westward. Planay, again, pushes the southern Dorans to east, allowing Domigny a little more elbow room; and les Almes allows the northern Dorans to approach the west, shyly; while keeping off the southern extremity of Mt. Vergy (the mountain of the Reposoir) at arm's length.

Further; the essence of the waves is their continuity. It may be obscured, but its law is strict. This range, however, begins in the south at Faverges, and finishes in the north at the monastery of the Reposoir; at either end the waves close round it,—most distinctly so at Nancy, near Cluses. We

have noted the wedge of Bauges, ending in a westerly deflection, and disconnected with that of Genevois; and we shall note that of Chablais, entirely isolated; though occurring on the general wedge-line, parallel on the whole to the waves. And here, within this middle range, the two chief summits, Sulens and Almes, are quite separate upthrusts of Lias and Trias. Around them everything is upset; round Sulens the cretaceous formations are violently disturbed; round Almes are faults and broken fragments of the beds through which the mass seems to have been thrust with violence.

Again; these summits are united to the Dorans-Charvin range by spurs, such as are never seen in the waves; except at the Coche, which, lying on the wedge, takes some of its features.

Lastly; the section shows the beds of Almes to be synclinal; in a wave they should be anticlinal,—more steeply so as the wave is higher. The whole line of the wedge is therefore both physically and geologically—both geographically and structurally—an intrusion.

The dislocation, so sketched out, is carried on in the western ridges. Their continuity is broken by great transverse valleys, whose origin arises between these four elevations—cracks started here

and extending right out into the plain. Between these cracks the land, already ridged north and south, is again ridged east and west, like a choppy sea under cross winds. We have seven lines in all, running on the original north-and south axes of elevation. And across these, four waves running east and west, as suggested by the four summits of the wedge (see plan, p. 43).

To expound the diagram, let us take first the parallel waves of limestone Alps, as in the description of the southern district; numbering them in the same order, with Arabic figures; and then we can describe the cross-axes of elevation marked by Roman numerals, as before.

The Waves.

First, the waves; which can best be traced by beginning with those nearest the wedge. The great eastern ridge (No. 6), continuing the Belle Etoile, has been glanced at; it is raised at points nearest to, and most influenced by, the wedge-summits; so that where Venesin, intruding at the most easterly point of the zigzag, withdraws its support, the great Charvin-Dorans range sinks to the only available pass across its long impenetrable wall.

No. 5,—Sambuy, dipping under the valley of

River Arve.

1. Sub-Alpine range. Petit Salève. 1.

VIII. 2. Breson. 3. Saxonnet. 4. Vergy or Reposoir. 5.

R Borne.

Grand Salève, Bellecombe; VII. *b* Couz. Fretes

VII. *a* Thorens. Verrerie. Glaire. Balme. Domigny.

R. Usses. R. Fillière.

VI. Parmelan. Lera. Achenaz. Balme. Traversière.

R. Fier.

V. 2. Veyrier. 3. Lanfon. 4. Cruet. 5 Tournette

R. Fier. Annecy Lake.

(Wedge.) *Sulens.* *Venesin.* *Planay.* *Almes.* (Wedge.)

6. Charvin, Charvin. Dorans. Dorans. 6.

V. VI. VII. VIII.

Faverges, rises again into the Tournette, itself continued northward in Traversière and Domigny. The Montagne de la Coche reappears in the Rochers du Cruet, whose twin ridge opens out into (on the right hand) the range of the Pointe de Balme, which finally unites with the Traversière to form Domigny and Vergy or Reposoir; and (on the left) into Mt. Achenaz, an unimportant ridge of Glaire. The twin Trelod is one with the Rochers de Lanfon, Lera, the Rochers de la Verrerie, les Fretes, and Mt. Saxonnet. And finally the Entrevernes range (No. 2) dips under the lake of Annecy at Duingt; reappears at that synclinal bank to the north of the lake between Talloires and Menthon, called the Rocher de Cheire; is broken off at a vertical fault, on the east-and-west axis of the Sulens-Veyrier cross-wave; continues in the great fold traced through the Veyrier, Parmelan, Thorens, Couz, and Breson. Looking at the map and key, and understanding how this southernmost cross-axis has already thrust up all the northern wall of the great break in which the lake of Annecy lies, the structure of this Rocher de Cheire will be readily grasped: how it is really the link between Entrevernes and Veyrier, which latter has just been broken from its chain and violently lifted, as the Lanfon and Cruet were

lifted; while the Tournette, though higher than either, has succeeded in raising itself with a less serious loss of continuity, being supported on tougher material, or on a broader base of upheaval, which tapers off to a mere string under the Lanfon and Veyrier.

The last of our southern ranges—Nivolet-Semenoz—it will be seen has still to be accounted for. M. Pillet has shown in his pamphlet on the geology of the neighbourhood of Aix-les-Bains that this is the southern continuation of the Salève range. And from the view now taken of the secondary Savoy Alps we shall readily see how strictly according to the law of their formation it is that this "Sub-Alpine" range should follow the thrusts of the wedge,—in being driven west, when it comes within reach of the first, or Sulens-Veyrier, cross-wave; so that the Montagne de Semenoz, disappearing in the streets of Annecy, reappears a few miles to westward at the Gorge of the Fier; passes northwards to the Pont de la Caille, and ends in the Salève itself.

The Cross-Waves.

Now to take the cross-axes of elevation, dependent on the wedge. Each of the four summits —Sulens, Venesin, Planay, Almes—lies in a cross-

ridge or narrow plateau, divided by ragged ravines, and crossed and masked by the longitudinal wave-ridges. No. V. (counting-in the cross-waves of Bauges, described in last section), the Sulens-Veyrier elevation, must be pretty well understood by this time. It raises the Tournette gently, the Cruet, Lanfon, and Veyrier each more abruptly. It pushes the sub-Alpine range far to the west of the southern district, and keeps itself as a whole a trifle to west of its northern neighbours. The next, No. VI., more to the east than the others, keeps up its breadth; and in Parmelan is even more extensive than in Venesin. No. VII. zigzags about in an undecided way; and indeed even the continuity of it is doubtful; for while Domigny is evidently raised by the same upheaving force as Planay, it is broken from its neighbours to westward by the great valley of the Bornands; and in Balme, Verrerie, and Thorens the influence of this cross-wave seems to merge with No. 2; while the Couz is separated from the Thorens by a great gulf, which shows how our four wedges might as easily have been five. The eighth and northernmost is simple enough; and creates the wall of the valley of Bonneville and Cluses. How far to east and west its influence may reach, none can tell.

Without a knowledge of the country, or many more illustrations of it than could be easily put together, the proof and conclusiveness of this simple disposal of so complicated a chaos of huge crags and chasms cannot be further insisted on. But the testimony of the map would be borne out by that of a well-made model of these mountains, in which it would be seen past a doubt, not only by the internal structure, but by the general conformation, that the whole shaping of the whole district is owing to two sets of physical forces—one crumpling the beds into north-and-south ridges, and the other raising and splitting them into east-and-west masses.

§ 3. CHABLAIS.

Although the districts between Bonneville and Annecy, and between Annecy and Chambéry, are properly and most characteristically the Savoy limestone Alps, with features all their own, yet the description of them is hardly complete without some slight sketch of the limestone and associated formations around. To the south, the ridges run on towards the Grande Chartreuse, which is but a few miles south of Chambéry; and present most of the same physical features as those of Bauges and Genevois. To the east, the central chain of the Alps, while offering

many points of the greatest interest both to the geologist and the artist, contains absolutely no limestone at all, except tiny remnants left here and there in hollows, and on heights from which it was not thrust away at the upheaval, nor has been denuded by subsequent erosion. For example, in the valley of Chamonix are remnants of lias still overlying the synclinal sweep of the gneiss, inlaid in its fold. It is to this we owe the tame foreground of the view from the Col de Balme, so unsympathetic with the gnarled and grand primary rocks which rise around and above it. On the Aiguilles Rouges and the corresponding range to the south, between Flumet, Ugine, and Beaufort, still more remarkably the lias reappears, inlaid here at great heights, to which the rising gneiss and mica-schists have lifted it in the hollows of their backs, and between the standing muscles of their knotty shoulders. The Aiguilles of Mont Joli have even raised and rescued a large plateau of Jurassic limestone, which remains as a witness to the fact that all this land was once a limestone sea, until the first disturbing revolution thrust its beds apart this way and that, tumbling and crumbling them about where the action was most violent, and only on the flanks of its upheaval are the secondary beds left in any continuity.

But both to the north and west of our district,

interesting developments of these formations occur; the northern neighbourhood, called the Chablais, having a distinct character of its own; and linking Savoy with Switzerland—through which these limestones run, parallel with the Alp chain, continuous with our wave-ridges in structure, but changing in many respects. And the western neighbourhood, the sub-Alpine plain and ranges, have much in common with the Savoy Alps; but gradually introduce new features and omit old landmarks, till we reach the Jura, which is a Savoy without its cretaceous strata.

Both of these districts throw indirect light upon the principal subject, and therefore claim a share of attention.

The Chablais on an ordinary map looks a mere chaos. In this simplified sketch-map, and still more simplified key, its structure is so apparent as to hardly need description in words, and a good model would force upon the notice of even the most casual and uninstructed observer, the systematic shaping of the whole by great general physical forces. A good model, however, is not obtainable, nor easy to make; while a mere raised map represents the character of mountains no more than a mould of blanc-mange can represent Mont Blanc.

The central Chablais is one great oval eddy or

system of ripples circling round a central spot, where is a unique and important intrusion of serpentine (marked S). It is as if, where a trout had leapt for a fly, the ringed wrinkles of the pool had suddenly been struck into stone, and the trout's intrusive nose left sticking there for a testimony. Round the serpentine are ranged, in rough concentricity, systems of corrugated strata, so exposed, that nearest the centre came the oldest, and on the borders the youngest. Thus Mont Marcely and the Roc d'Enfer are liassic, while both the Voirons and the Buet-Midi chain are capped with gault and flysch. This broad single intrusion is only a continuation or re-appearance of the wedge which holds apart the ranges of Genevois; but here more strongly developed, and with influence more widely extended. And the Varens-Buet-Midi continues the Belle-Etoile-Dorans, though with much irregularity; and passing through the Dent de Morcles, runs through the Oberland by the lakes of Thun, Lucerne, and Wallenstadt to the Vorarlberg.

The Chablais is not one great anticlinal, though showing in its central part the features of one. For besides the faultings, which like those of Bauges throw down the crumpled strata in the west into parallel waves, half smothered in their own ruin,

the whole is tilted on the flank of Mont Blanc; from which it happens that the upper secondaries which make the floor of the plain to the west, make the roof of the plateau to the east.

But further; it is only the central district of Chablais that this intrusion or wedge seems to affect: the rest is thrown into the normal parallel ridges which we have seen to characterize the Annecy mountains; so that, first, the Chablais is a country of parallel waves, running N.E. and S.W. Into this, about Mont Loi as centre, is thrust the wedge, pushing out Jouxplaine and Criou on one hand, Marcely and Chery and their rear ranks on the other; then crushing all the land between the Mole and the Varens massif against Mont Saxonnet, the Breson and the Vergy; and finally doing as much mischief as it can in thwarting the orderliness of the ranks to north-east; for see how Hautforts, Montriond, and Lens have been thrust against the Roche Grise, Chesery, and Grange respectively, fairly doubling these up, and only allowing their northernmost extremities to retain anything like their normal regularity.

As before then, there are two motives of elevation to be considered; the parallel wave-structure of the Alps, and the subordinate dome of this confused local anticlinal, centring about this intrusion

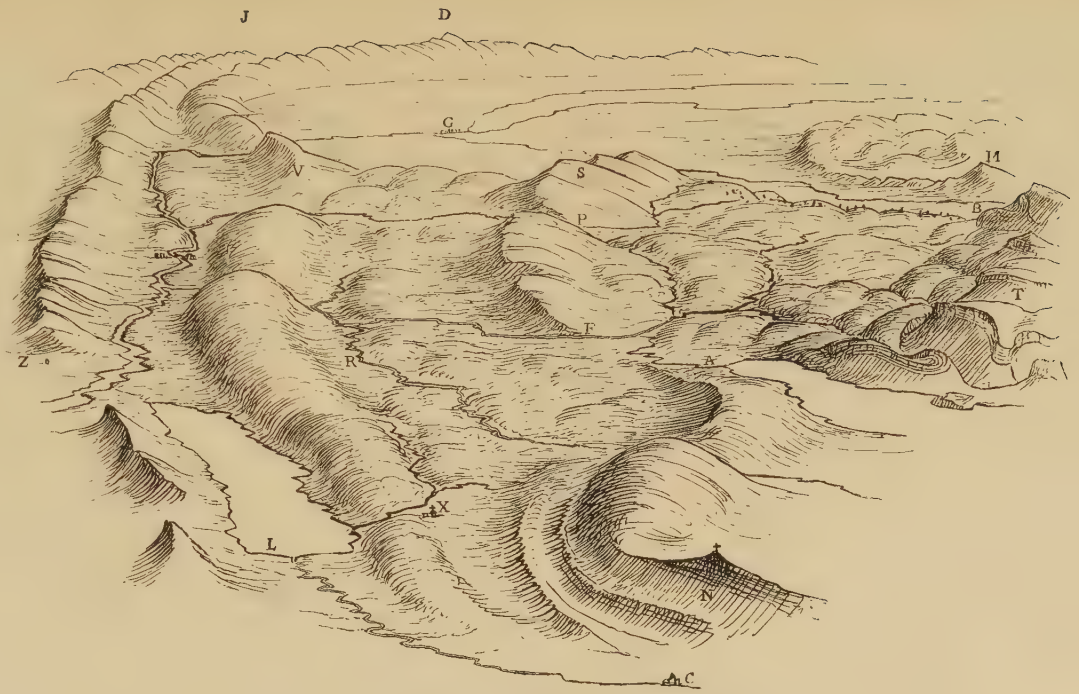
of serpentine, which represents the wedge; only that the wedge was formerly distributed over a number of points along a line; here it is all concentrated in one great upheaval, or close cluster of upheavals.

Over great part of this district, as over the Jura, the Urgonian formation has never been laid down; and the lias and trias have also been thrust up so sharply, that a merely geological and not physical examination could not suggest any continuity with the rest of Savoy. As it is, we see here almost a chaos, and yet the liberty of its plan is curbed, indeed created, by strict law. But had the great craggy limestones existed here, they might have made central Chablais as gnarled a knot as any in the world.

§ 4. THE SUB-ALPINE DISTRICT.

The Salève Range.

The bird's-eye view of the sub-Alpine district illustrates the general physical aspects of the transition from Alps to Jura. On the right hand are the Alps, from the Voirons to Bonneville; then the broken fold or rolling wave from the Breson to the Montagne de Veyrier. After an interval of comparative repose, or at least concealment of the strata, beneath the molasse-mounds of les Bornes,



VII.—BIRDSEYE VIEW OF THE SUBALPINE DISTRICT.

A. Annecy.
B. Bonneville.
C. Chambéry.
D. Mt. Dôle.
F. Gorge of the Fier.
G. Geneva.
J. Jura range.
L. Lac de Bourget.
M. Mt. Mole.
N. Dent de Nivolet.
P. Pont de la Caille.
R. Rumilly.
S. Mt. Salève.
T. Mt. de Thorens.
V. Mt. Vouache.
X. Aix-les-Bains.
Z. Culoz.

comparatively a plain, the sub-Alpine range begins at a distance, in the Salève; rising just on this side the river Arve, which flows from Bonneville to Geneva; banked to the north by the Jurassic wall of Faucigny and the Mole; and to the south by glacial boulders, roughly indicated in the sketch by a line of black dots. The sub-Alpine range, cloven once at Monetier, the pass between the Little and the Great Salève, is again cloven at the Pont de la Caille, where the river Usses, rising among the molasse mounds, rushes through a remarkable chasm, over which the high road from Geneva to Annecy passes by a well-known suspension bridge. There are other unimportant breaks in this range between the Usses and the Fier; at the Fier another break, accentuated by a deep, eroded river-gorge, one of the most famous and fashionable sights of Savoy, corresponds with the cross-valley in the limestone Alps in which Annecy lake lies; just as the gorge of the Usses might be regarded as the continuation of the crack which separates the Montagne de Thorens from the Parmelan. Indeed, if one could make a model of the limestone sheet overlying the whole land, stripped of partial covering, crumpled up into its ridges and folds, and cracked across where the transverse valleys come, we might be able to represent the

cracks in this sub-Alpine range by continuations of the cracks across the higher Alpine chains. The gorge of Monetier, which has so puzzled geologists, might then be seen to be a continuation of the Gorge des Evaux between the Breson and Couz; or of some such crack. But this is a mere suggestion, which we have no means of verifying.

The segment of land immediately to south of the Annecy valley is, we have seen, correspondent with that to north; but lying more to eastward —so that for the continuation of the Salève chain we must look to the east: accordingly at about the distance at which we might calculate to find it, we see the limestone crop out in Annecy, rise rapidly behind the town, run along the ridge of Semenoz, and break off at the valley of the Chéran.

South of this again the land has been thrust westward, and we accordingly take up the clue, a little to west of where we dropped it; follow the mountain of St. François de Sales (sometimes improperly called Mont Azy), and the Mont de la Cluse, between the Desert of Bauges and the valley of Aix; ending, as far as our district is concerned, with the Dent de Nivolet, and its white cross and precipices, over Chambéry.

M. Pillet has already, independently of this train of thought, traced the continuity of the sub-Alpine range; whose chief distinction from the Alpine chains is the appearance and importance of lower limestone beds, not merely as base, but as summits. In the Alps, the summits are nearly always Urgonian, or something more recent; or else Lias, or something more ancient; with the exception of the Montagne de Couz, where the Neocomian, finding itself folded in between two layers of Urgonian, and then deserted by the top crust breaking away, was forced to remain and play the unwonted part of a peak. But in the sub-Alpine range, whether from thinning of these cretaceous beds, or from greater strain and breaking of them, or from both causes, the summits are generally Neocomian, the Urgonian beds creeping up behind a great central core of the older stuff. Then in the Jura we lose both Urgonian and Neocomian, and find summits of strictly Jurassic rock. That is to say, the area over which the cretaceous formations were deposited to their full thickness does not extend westward of the wave-line No. 2 (pp. 34, 43). As these strata by their massiveness and cohesion are specially apt to form the great crags and slopes which characterize the Savoy Alps, the absence or diminution

of them naturally coincides with the absence or diminution of their typical aspects.

The Chambotte Range.

Between the sub-Alpine range and the Jura is one chain not typically Jurassic, and yet distinctly connected with undoubtedly Jurassic hills. The inner line of Jura, trending round the lake of Geneva, flanking the Dole, broken at the river Rhone by the ravine of Fort l'Ecluse, reappears across the Rhone in Mount Vouache. This gradually sinks into the plain once occupied by the sea wherein Urgonian soil was deposited; and rising again south of the Usses, opposite Seyssel, continued south of the Fier, as Mount Chambotte ("Jambe haute," compare "High Stile" of our own Lakeland), disappearing from Aix-les-Bains to Chambéry:—this range now, being in an Urgonian country, bears Urgonian soil on its back. For though the full thickness of Urgonian strata is confined to the Alps, the formation extends to the south-west in some volume, thinning considerably in the north-west. But these lines of mountains run across country without respect to the formations which lie at the surface; as again they do in Chablais, where, in following an outcrop, you cross several ridges one after another. So

that here, again, the stratigraphy gives no clue to the physical structure, which can be traced only from the geography.

The Jura.

Between this range and the next the Rhone runs for part of its course, and the Lac du Bourget lies, in a hollow dammed by drift. The eastern wall of this long valley continues the second rank of true Jura mountains, showing all the geological features of the Jura in its northern parts; but at Culoz, being come into the Urgonian country, carries Urgonian beds on its sides; and in the Montagne du Chat we have all the cretaceous formations present, with most of the Jurassic, all of which are absent in our district of Savoy Alps, except the Oxfordian.

The Lowlands.

Between these ranges everything is filled with Molasse, a soil formed like Flysch, but later, from the *débris* of the upheavals, and contemporaneous with their latest periods, having itself undergone considerable dislocation and tilting. The Molasse itself forms hills which in a plain country would be noticeable, but here seem the merest mounds.

And between the Salève and the Vouache is that great moraine capping Mont Sion, the relic of the great Rhone glacier, and ancient dam which restrained the great sheet of water now shrunk to the lake of Geneva.

CHAPTER III.

THE SECTIONS.

§ 1. THE GENERAL STRUCTURE.

FOLLOWING out the metaphor which likens our Alps to "Temples of Nature," or what you will, and their plan to an architect's design, it is no great stretch of analogy to match the building of their walls and domes with the structure of a bastioned battlement or shrine with buttresses. It is not unfair to describe them in the same terms, nor unwise to criticise them according to the same canons. The earliest human building is only an imitation of Nature's masonry; and the latest must conform to her customs, even to placing the very stones as she laid them at the beginning; or the laws of matter will deny it strength, and the laws of mind will disallow it beauty. For these rough sketches of the elevations or sections of the Savoy Alps, inadequate as they are, suggest, at one and the same time, possibilities of every noble form and every condition of stability.

It is not from the timidity of our little hills that

these are secure;—"he that is down need fear no fall"—what thanks to him or his fortunes? But see in these sections what steeps, what walls, what towers, what pinnacles!—and these are here drawn to a scale admitting no exaggeration of steepness, while it represents ten thousand feet by half an inch.

The size of these mountains is too enormous to be easily appreciated; the English eye finds them out of all proportion to anything it is wont to measure, and simply cannot cope with them,—miscalculating its resources and misapplying its reasoning, like a Cloten wooing a princess. There is glamour in the pellucid air, which affords none of that convenient aërial perspective on which artists of these Cimmerian regions rest their hopes. There is deception in the massive simplicity of the crags, as in a well-proportioned tower of great stones, or in a broad-shouldered giant. There is delusion in the very trees that clothe the slope or crown the summit; you took them for creeping copse or fringing bracken, and resent being told that they are huge Scotch firs, any couple of which would make a complete subject for an academy landscape. At last you wake up to the fact of their hugeness,—take your glass, and examine that little patch of brown litter in the green field: the nebula resolves itself into a village. And where you saw nothing

before, new constellations of kine and a whole galaxy of Alpine goats heave in view. Fascinated by the mountain glory, you would gladly find yourself in that earthly paradise; but half a day's pilgriming up a very Jacob's ladder brings you barely within reach of your Beulah.

Though these Alps shirk no audacity, they secure complete solidity. Take as an example such towers as the Rochers de Lanfon, the Cruet, the Trelod; such walls as the Dorans, the Traversière. How can they slip, with every brick well set back in its bed; every bed well bound from behind by all the powers of gravity? Savoy is not careless of the laying of her masonry,—no such thing. Rather, one might cavil, over-wary; for her highlands stand shoulder to shoulder, heels well into the floor; heads back; breasting the world.

Among these limestone Alps, while the profile is uncompromisingly precipitous, it is most rare to find that waste of shattered scree which makes so unpicturesque a pedestal and so inhospitable a stairway to other crags, whether the gneissitic giants of Switzerland, or dwarf slates of Westmoreland, or any precipices which have not been planned according to the architectural rules of Savoy. The talus under our great walls is not rubbish; it is rock;—a pyramid of Neocomian

brickwork beneath a pile of Cyclopean Rudisten-kalk; and if anything falls from overhanging balconies or pinnacled cathedral-roofs, it is only an occasional block.

This is owing to the set of the beds, shown in the sections, by which every course of stone slopes backward, downward, from the face of the wall; so that there is no inducement—no starting-point, even—for disintegration. Materials of the flimsiest, so placed by such a light and lucky hand, must hold up to the crack of doom, against frost and fire, drought or deluge; and once fixed and founded well, can be undermined only by percolating streams and chemical corrosion.

With her vaults, Nature is, in a way, not so successful. It is common enough, indeed, to see a perfectly continuous arch, like the waggon-roof of an early church. But oftener the outer crusts of Urgonian and Neocomian have been strained to cracking over the bent Jurassic beds; and generally speaking, the sharper the bend, the stronger the break. For example, note how the Breson, Parmelan, and Couz, break into crags; the Traversière and Domigny burst into valleys; the Chambotte and Semenoz merely lose the ridges of their outer vaulted shells; while the Vergy (mountain of the Reposoir), Saxonnet, Achenaz, Breson-flank, and

others, retain the whole arch in sleek simplicity of curve.

Notation of the Formations.

In these figures, the upper broad layer, divided by a fine line, crossed by vertical fissures, and lettered U, is the Urgonian; playing everywhere a very prominent part; not only piled in sturdy precipices, but switched about like a whiplash into loops and curls. At first, indeed, it seems almost too hard to believe that so solid and rigid a stuff should lend itself to such flowing and fantastic lines; and quite too hard to imagine what process could have produced them from original flat layers. But there are places where the twist is indubitable to the naked eye in the naked rock; notably in the Jurassic beds at the Nant d'Arpenaz.

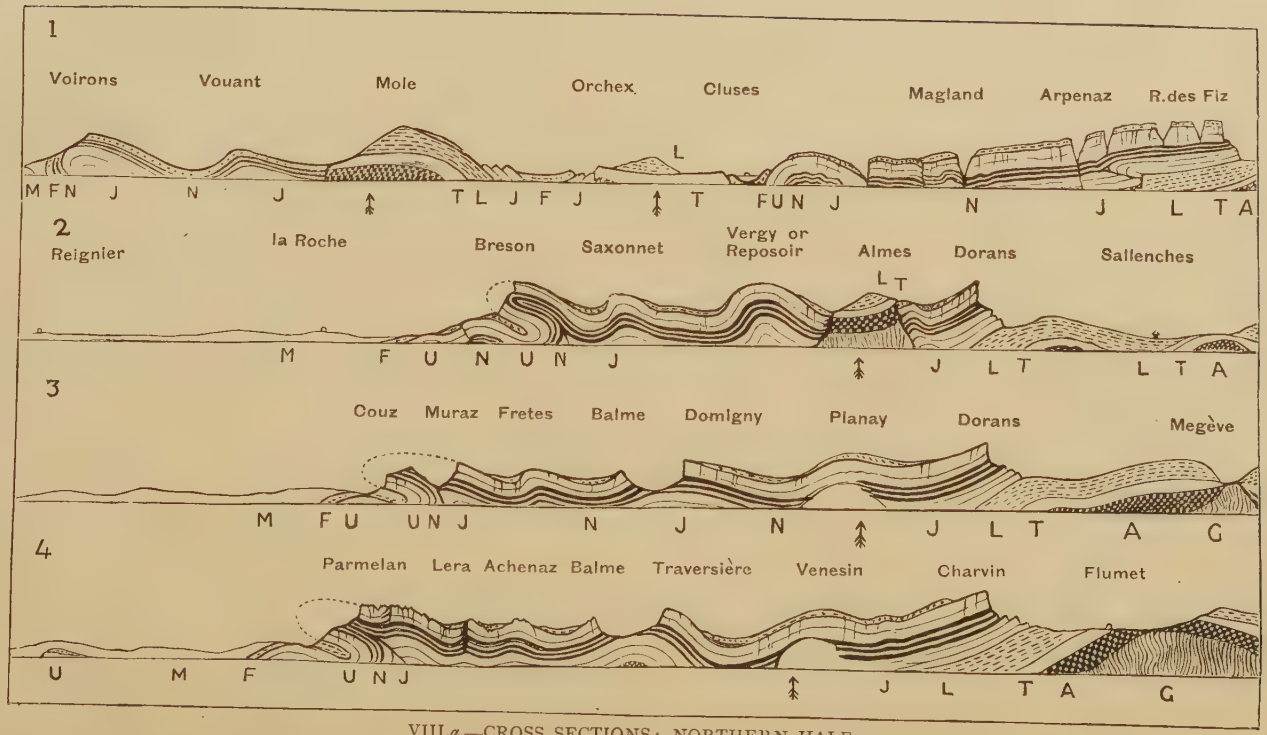
Above the Urgonian generally,—below it only when the beds are reversed in folds and loops,—a row of dots, marked F, denotes the Flysch. The line below the dots may stand for Gault, Grit, and Chalk; unimportant in nature here, and on this scale and for this purpose quite indistinguishable and unnecessary. The line above the dots will do for Nummulitic Limestone, though it has generally been stripped from the Flysch, except in sheltered hollows.

Below the Urgonian, three dark lines mark the Neocomian, lettered N. Below that, three light lines, J, the Jurassic, down to Lias; its stages not individualized, because though their irregular development is a remarkable fact, it is more important in the geological history than in the architectural structure of the country.

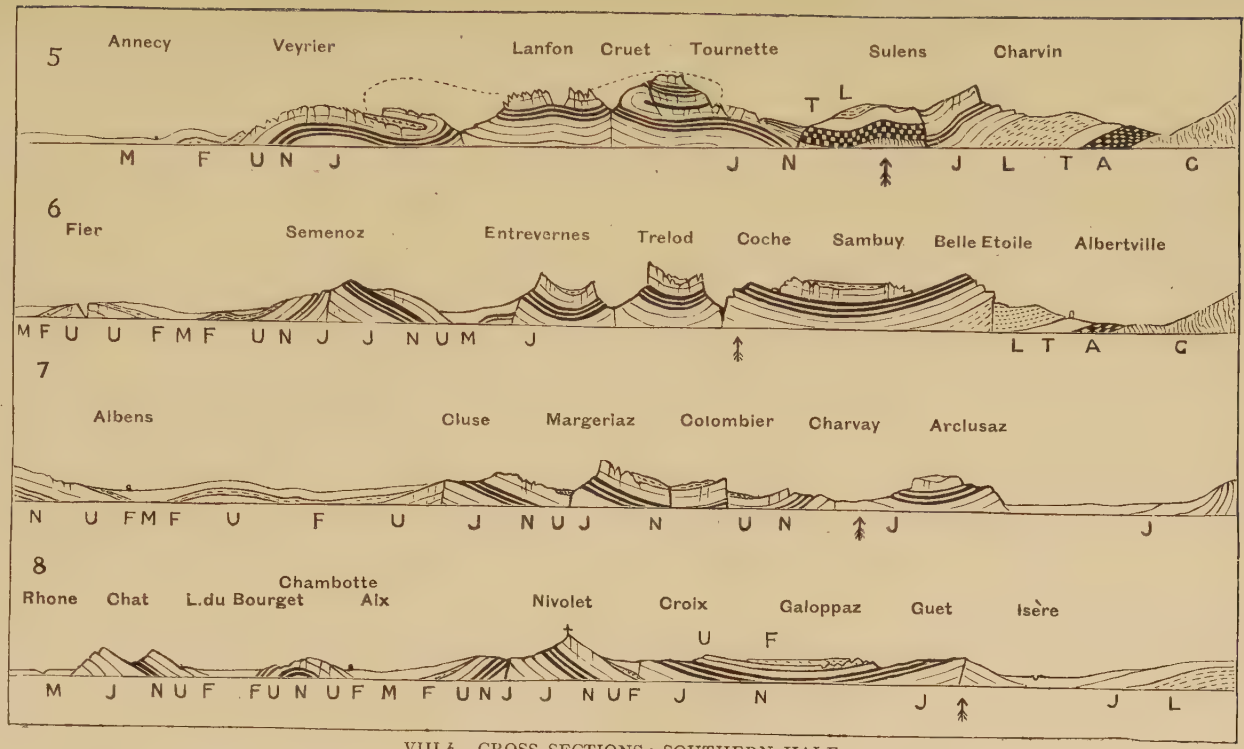
Then L, with broken layers, for Lias; T, plain white, for Trias; A, chequers, for Anthraciferous formations; and G for the Gneiss and other crystalline rocks of the great Alps.

Lastly, to the left hand, the little hills marked M are Molasse, whose mimicry of the tilting and writhing of its great neighbours hardly claims the condescension of a general section.

The parallelism of the subordinate Alpine waves, and their continuity, exhibited on the ground plan or map, is shown no less in the general sections compared with one another. Every fold, every crack, in any one, is reproduced in its neighbours to north and south, though with such variations of design and detail as appear in every natural work,—"organism," one might almost say; for if unity of purpose, obedience to law, continuity of history, be tokens of organic life, these are as much the subject of geology as of anatomy.



VIII.*a*.—CROSS SECTIONS: NORTHERN HALF.



VIII.*b*.—CROSS SECTIONS: SOUTHERN HALF.

Cross Sections.

In Plate VIII. are arranged eight slightly sketched and roughly generalized sections across country at about equal intervals, from Faucigny, on the north of Bonneville, to the Nivolet, above Chambéry; the northern to the top and the southern to the bottom of this page. The summits of that long escarpment which fences the district from the central Alps are placed one beneath another, as they have good right to be, for the line is very nearly straight. Only, in the southernmost, where, as already shown, Armenaz finds no cretaceous continuation, it will be seen that this escarpment is no longer to the east of the "wedge" (marked throughout by an upthrusting arrow); but the wedge has taken its place; and the block of Urgonian which ought to be found there has been torn off and cast aside as *débris*. And yet the actual wall of the Isère valley we have kept in a straight line with the range whose place it presumes to take, but only for the sake of dragging in the sub-Alpine and Jurassic ranges to the west.

First, the wedge. In the lowest lines it appears as a mere fault, above which, however, the cretaceous beds have been carried away. And yet it is not so much a fault as a burst upthrust, as in section No. 6, marking the valley between the Trelod and

the Sambuy (valley of St. Ruph). This fault, and the string of Oxfordian which accompanies it, now trends to westward round the Rochers de Lanfon, and loses itself between Alex and Menthon.

The wedge, thus thrown out, has to make a fresh start; and so, across the valley of Annecy, it reappears more to the east, breaking right through the cretaceous beds above it, with such a clean sweep of them, and even of part of the upthrust Lias, as seems to imply some violence of action. To the east, the cretaceous beds are very little stirred, not at all contorted, and simply tilted on the flank of the central upheaval; while to the west the flat surface rolls into waves, and the waves into breakers, till they die out on the plain. And these waves and breakers are violent just in proportion to the importance of the wedge; in the south very little contortion; more towards Bauges. At No. 5, where the wedge reaches the surface, upraising a mass of Lias and Trias, not only is the breadth of the district greatly enlarged, but both the waves which form the Mt. de la Coche and Mt. Entrevernes, by simple dipping (for all one can tell) here, in the Tournette and Veyrier, break over into folds; in both cases conspicuous, so that the Veyrier is the *locus classicus* to study such a structure, and the Tournette's very name

means a turn-table, or the whirligig of a squirrel's cage.

Just north of Thônes, where the wedge does not rise to the surface, and betrays its presence only by the bulging of the beds, both the contortion and cracking are milder. The Tournette's twist ought to come between the Traversière and the ridge to the west, whose highest peak is the Pt. de Balme; but as this piece is wanting in both No. 2 and No. 3, it is impossible to do more than guess whether the fold may or may not have been continuous, and it is not necessary for the continuity of the formation, that the wave should here fold over from its arch into a loop. But the Mt. du Reposoir (Vergy), as the map shows, unites both ridges; namely, the Balme, which continued the R. de Cruet over Talloires;—and the Domigny, which continued the Traversière and Tournette. In fact, the great wave next to westward of the wedge has been split lengthwise from the middle half of its course, leaving the ends united—one being the loop of the Tournette, and one the almost-loop of the Mount of the Reposoir (Vergy); continued in the mountain on which stands the little village of Nancy, and then, after a cloven ravine—"Cluse," in Alpine French, whence the name of the village at its mouth,—the same structure is continued in that most remarkable

"waggon-roof" which reaches to St. Sigismond, and forms such a feature as you approach the Alps from Bonneville.

To take, next, the waves as seen in the cross-sections. That to eastward of the wedge is the long escarpment or moat-wall of the central Alps, already mentioned. Its structure in section is simple; the slowly rising beds are suddenly broken off; and there is an end of them. As you cross the Alps, a remnant here and there may perhaps be seen; a scrap on the top of the Aiguilles Rouges and Mt. Joli, another at the bottom of the valley of Chamonix; but these Cretaceous and Jurassic soils never appear again until you reach the borders of the great Lombardic plain. The sharpness of their break, the completeness of their absence, is one of the remarkable points of this remarkable subject.

In this otherwise steady slope there is a remarkable twist, seen only, but I am not sure about this,* in the Jurassic (Oxfordian) beds: and very markedly at the Nant d'Arpenaz, between Magland and Sallenches. To the north, it seems to reappear

* I find in Professor Alphonse Favre's "Recherches Géologiques," § 427, a description of this Jurassic twist as seen from the Criou; in which he remarks that the cretaceous formations are *not* twisted, and believes that the Jurassic are not unfrequently contorted independently of overlying strata.

under the Pointe Pelouse, and in the spur thence toward Sixt. It may be traced also on the opposite bank of the valley at some height, beneath the crests of the Dorans, along and under which it seems to run. If not the effect of an earlier earth-creep, such a structure might be produced by a blunt wedge, whose pressure upon the lower strata was greater than upon the upper. The suggested up-thrust under Mt. Planay (section 3, Plate VIII. *a*) would fold up the Jurassic beds, while merely arching the Urgonian.

The westernmost wave of this sea of limestone breaks on the lowlands; and, in breaking, curls over into the most conspicuous of convolutions: seen in the Breson, the Couz, the Mt. of Thorens, the Parmelan and the Montagne de Veyrier. South of Annecy this line is continued in the Entrevernes and Margeriaz, though the loop is not so plain. The dip at the Col de Rampon in the middle of the Mt. de Veyrier reappears on a lower level after a fault, in the Rochers de Cheire, or Promontory of Talloires; this on the other side of the lake becomes the peninsula of Duingt, and the valley of Entrevernes. The fault that bounds this mass on its western slope throws down the last roll of cretaceous strata as they plunge into the low-land; hinted to the north in a slight downthrow

on the flank of the Breson, observed in the Gorge des Evaux. The line of this long fault carries us south across the valley of the Chéran, and round Mt. Margeriaz; which seems to be the true continuation—rather pressed out of line, and broken short off on its western slope—of the lower fold of Urgonian in the Breson, and of the long crest of the Mt. of Veyrier.

Contortion takes place in the outer rings to the west and north; in the parts furthest removed from the disturbing influence. And generally speaking, it must be vividly noticed that near more elevated centres are created faults and fissures; while surprising folds and convolutions, such as those of the Breson, and in Chablais, the Voirons, are quite on the outskirts of the disturbed region, suggesting that for their production a slower, steadier pressure is necessary. The Voirons are a remnant of a roller of rock, like the Veyrier-Breson chain, plunging on the plain of Lake Leman; just as it is only the most shoreward wave that actually curls, and coils, and crashes on the beach.

The Dent de Nivolet, remarked from the Montcenis road between Aix and Chambéry for its white cross and abrupt peak, is a type of one form of limestone architecture. The beds rise slowly from

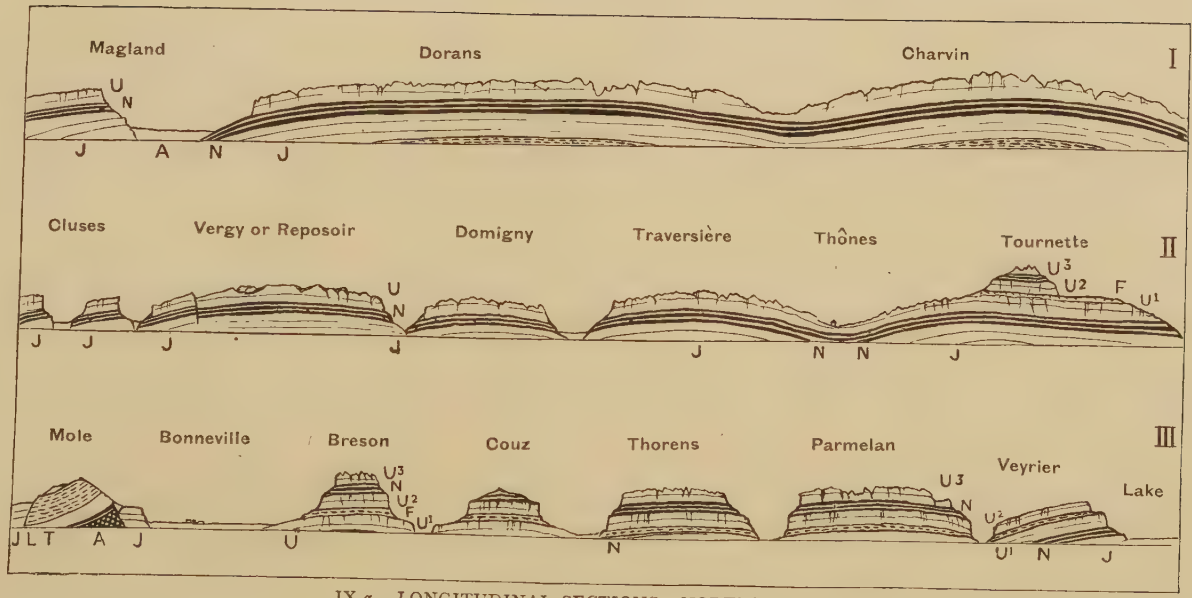
behind, out of that upland valley called the desert; and at a height of 1,553 mètres are suddenly broken off, sheer down to the plain; and that on two out of three sides—something but not quite like the Angle of the Salève. This truncation of the folded beds, which forms the valley near Chambéry, is most striking and most noteworthy. Toward the east the truncation did not occur, but the beds dipped into a synclinal;—here the dip is slight, if anything; but a great ditch has been dug or torn across them. And the same phenomenon is shown in all the great cross-valleys; Veyrier and the Mole—the north-western banks in each case—are thrown sharply up, while the opposite banks slope (in the main) gently down.

Going north from hence, along the westernmost ridge, we follow a fault, from Aix to Annecy; and something more than a fault, for the strata as there observed are not merely disjoined, but entirely unconformable. In fact, the whole broad ridge is the remnant of a loop, or breaking wave, of which the broken top has crumbled away, as it was likely to do. Indeed, when one speaks of an S fold, in rock of this nature, it must be only by analogy; for it is hardly probable that such a substance, not being either very elastic or very plastic, ever took or maintained such a shape in

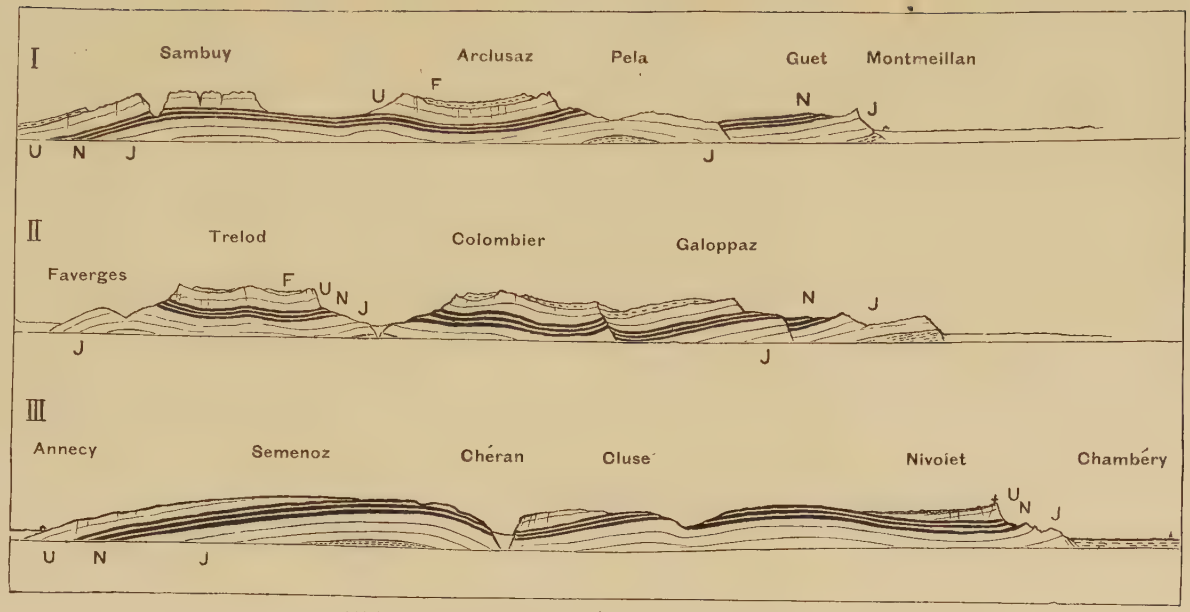
complete continuity. It must have been pressed laterally until the resulting dome rose higher and higher; finally falling on one side, no doubt in ruin. It is the back of such a roller that makes the Montagne de Semenoz so conspicuous above Annecy lake; and the break of it which shows such striking steps towards Rumilly.

The central ranges of Bauges (known north of the Chéran as Entrevernes and Trelod) are remarkable examples of the twin-crest shape; synclinal high-raised valleys, separated by anticlinal ravines. It is a most striking and instructive view from Talloires, that of these rolling curves, crags, and slopes; showing all the construction more plainly than any diagram. Only from this point the Mt. de la Coche is not seen in profile like the others, and its flank shows backs of Jurassic beds in a sort of "three-quarters" view, as a portrait-painter would say. Here is a case where simple inspection is not sufficient for the understanding of the lie of the land; the secret being in the difficulty of recollecting one's "bearings" in looking round a panorama; and in the different appearance of a well-known structure seen in unaccustomed situations.

For these beds, whether Urgonian or Jurassic, have quite different aspects according to the position



IX,*a*.—LONGITUDINAL SECTIONS: NORTHERN HALF.



IX.*b*. –LONGITUDINAL SECTIONS: SOUTHERN HALF.

in which they are seen, or the parts presented. Broken perpendicularly across the plane of bedding they exhibit whatever cleavage is there to see, together with a vertical rifting, the result of weathering and the force of gravity;—broken at various angles across the beds, the same aspect variously distorted. But the bent and bared backs show no cleavage, only a sort of fluted or scaly undulation in bosses and ridges more or less continuous and following the arc of the bend.

Finally, it must be noted of these Alp-waves, that their wave-character shows itself in the softness of their terminations, when they do terminate; and in the way in which one grows into another in continuity more of substance than of actual form. So that the geometric parallelism is rather in promise than in performance, after all; though the continuity of mass—conservation of matter, if one may so call it—is as strict as it is striking.

Longitudinal Sections.

To take now the longitudinal sections, on lines running north-east and south-west; not quite straight lines, nor following the main ridges in their true sequence as explained in Chap. II., but comprehensively reviewing the general structure of the continuous parallel ranges.

The mountain masses are raised into arches; the valleys are either synclinal troughs or breaks, generally both; and in every one of the three great valleys there is a sort of fault which throws down to the south—so that the northern face presents a section of the three great formations, while the southern is formed by the upper beds sloping more steeply down to the trough (see p. 67). Here the mountains appear to have been hoisted up and dragged apart; but seen in the cross sections, they have evidently got their arched and ridged form by being crushed together. And while the valleys here look like deep cracks, in Plate VIII. they are merely superficial folds or unimportant scars.

In the double illustration (No. IX.), they are arranged so that the sections of each half, Genevois and Bauges, can be seen together at a glance. The first, second, and third of the former lot fit on to the corresponding sections in the latter; so that the continuity of each great cross valley is brought into more emphasis. Thus Magland, Cluses, and Bonneville mark the great cleft of Faucigny, Faverges and Annecy, and Montmeillan and Chambéry the other two principal valleys. The valley of Thônes continues itself through the gorge between the Mt. of Veyrier and Parmelan; that of the Chéran

runs up behind the Trelod. The subordinate cracks which dislocate the southern district are not given here; these sketches being only suggestive (like the map) of the general structure of the country.

The westernmost line—Bonneville, Annecy, Chambéry—is difficult to represent in section, because the vertical plane here cuts through the great fold already described and illustrated in the cross sections; the three beds of Urgonian in the Breson, Thorens, and Parmelan are owing to this fold,—while in the Couz and Veyrier the upper bed is wanting, but reappears, as the cross sections show, at a little distance behind.

In the Semenoz, which lies in the same line with the series just described, though not structurally continuing it, there is a curiosity of structure to which this longitudinal section cannot do justice. It is a broken loop or arch, like a more timid Breson, or a more audacious Chambotte. The folded edge has broken away, both Urgonian and Neocomian—here beginning to lose their Alpine strength and mass—and exposes the Oxfordian, faulted or apparently faulted where the two lips, so to speak, of the face of the land meet and pout The cross sections of this have been described: the longitudinal sections show that the loop is not so

far folded as that of the Breson range; and that the Urgonian is less important, here and there even disappearing, as both sections show.

The middle and eastern lines are simple enough, with the exception of the Tournette, whose summit, like that of the Vergy, is a junction of two ridges, and is crushed into folds by the energetic pressure of Mt. Sulens.*

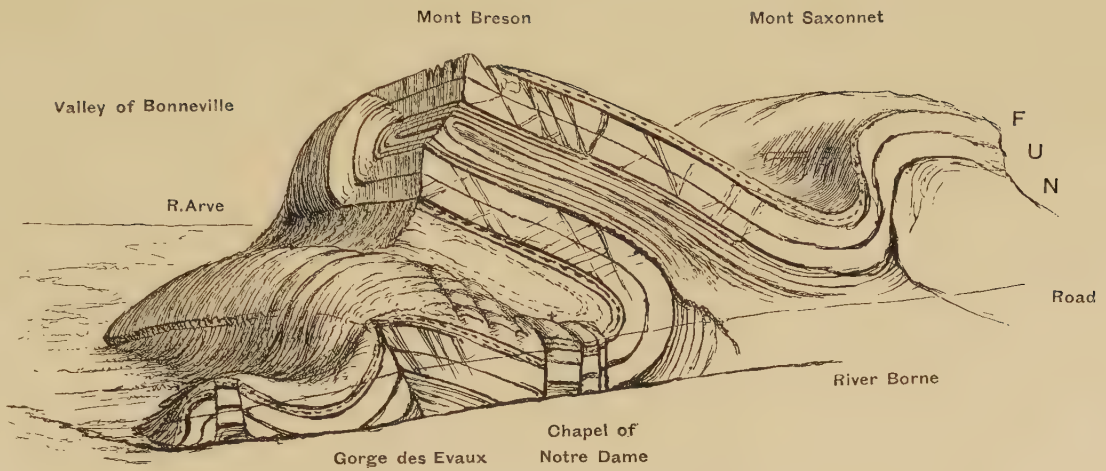
§ 2. SPECIAL ANALYSES OF SEPARATE GROUPS.

The Breson.

The long fold or wave-roller which reaches from Annecy to Bonneville ends in the Breson; and nowhere is it seen with greater completeness, for in all the other mountains which it forms, much of the characteristic bend is obscured or broken away. But the Breson, whether seen from Laroche or from the valley of Bonneville, strikes one first by the long roll of its flank, and then by the double precipice and slope which make it most typical of Savoy.

Not only of the geological structure is it typical, but of everything poetical in this land of romance. Seen from afar, the sweetness and strength of its rolling curves, sweeping slopes, or rugged crags, whether in time of snow or summer greenery, combine into a marvellous grace and majesty of

* But see postscript at the end of this chapter.



X.—ANALYSIS OF THE BRESON: SEEN FROM THE WEST.

form, harmonious as some perfect piece of Phidian design. And, as you approach it, threading the orchards, rosy with blossom, or ruddy with fruit; tracking the mill-streams to their source,—clear wells that bubble through the cyclamen,—cascades that leap miraculously from the unriven rock; as you follow the swift Bronze to its fairy glen, a Tempe of marbly colonnades, mysterious pools of eddying emerald and diamond bursts of foam; as you gaze aloft at sumptuous slopes of walnut, and hanging gardens of pine; and higher, at great rearing precipices, shadowy beneath the afternoon, and purple against broad leaves suffused with sunlight; and higher, at green glimpses of pasturage, perilous, it seems, and unapproachable, where you can tell that the wind is blowing free, and little bells of innumerable flocks are tinkling; and higher, and higher, to the craggy crown of all, wreathed with cloud, gemmed with snow, away in the blue;—aye, here is the scene that poets have dimly dreamed and painters have striven vainly to present; all the Greek lyrist's fairyland, all Homer's hero-world.

Is it not good to be here?—not uncompanioned, if we could call to share the scene, passionate and reverent, some true-lover of the mountains, like those hero-poets of the Greeks. Would they not

dearly love this darling Ida of the Alps, the Parnassus of Savoy ?

Is it, though, so good to be here ?—seeing we cannot choose our company ; for here comes one shouting to us that we are in danger—" They are going to fire a blast ! " he says.

They are road-making on the Breson ; come away across the valley. You notice the little red flags along the fields ? that is where the Chamonix railway is to come—" To bring us French wines and wares, and plenty of English tourists," say the delighted natives. And now you can see the great scar, raw and livid ; slashed through " the pure lines' gracious flow," marring the sweet curves and soft modelling of the lacerated breast ; with hideous waste of ruin fallen from it, tearing the verdure from its bruised and broken anatomy. That is the new road to the village of Breson, on the mountain's shoulder ; soon to be a splendid sanatorium and fashionable summer resort. For who says the modern world does not love its mountains ? See how it woos them and wins them, the ardent bridegroom,—paws and paddles them over, till all their virginal front is fouled, all the honour of their divinity is lost ;—poor darling Ida of the Alps, poor Parnassus of Savoy !

The frontispiece is a rough sketch of the Breson,

taken one winter's morning from the further side of the Arve, halfway between Bonneville and Scionzier. The snow, thinly strewn on everything, threw into stronger relief the dark crags and lines of leafless trees, emphasizing every great black fir upon the rolling slope to the right, and the crisp fringe on summits to the left. In front is seen the spur of Mt. Saxonnet, with rocks showing that fluted and scaly aspect which marks bared backs of bent Urgonian ; an aspect repeated higher up, on the Breson's shoulder. Between the two mountains runs out the Bronze, joined by streamlets which have worn themselves water-courses from the Breson's lap, or which rise from fountains under cliffs at its feet. Up the skirts of the mountain the new road climbs, incomplete, or concealed for a space, and then re-appearing on the shoulder in naked rigidity. I beg the reader to cover this hard line in the frontispiece with the forefinger of his left hand, and consider whether the whole mass of mountain does not gain a quite unthought-of dignity and sweetness—poor though the sketch be. The whole effect of the natural composition of the lines is ruined by that road, just as a face by a scar, or a figure by ill-disposed drapery. And when you have looked for a minute at the frontispiece, alternately covering and uncover-

ing the road, you will be disposed to use violent means to do away with that distressing, irritating intrusion. Of course, the engineers and other interested parties do not feel distressed by that road-line; they would be only too glad to make it a railway-line. And the public sees no harm in it; not perceiving that it has come to the mountains for inspiration,—bodily and spiritual; but has brought in its train just the very influences to foul the clear Alpine air, and cloud the atmosphere of beauty and romance which Pharisees and publicans alike have swarmed out into the wilderness to find. It is not surprising that so many tourists annually come home so "disappointed with the Alps!"

There are to be noticed in this view, first, the double precipice of Urgonian, connected by dotted lines to show the unity of formation; not to suggest that the beds ever took that complete curve in full continuity, for they most probably would break away during any process of folding, like the outer layer of a sandwich. Between the two Urgonian walls is a grassy slope of Neocomian, and behind the summit long stretches of Flysch and Nummulitic limestone—the same formation re-appearing in the hollow of the lap (F. F. *n.*) Secondly, note this lap and great vault or waggon

roof, plunging into the plain, and broken only by a cornice, which emerges from the valley-bottom at the extreme right of the picture, and runs up and along the northern side. And thirdly, under *n*, a vertical division seems to separate the front of the mountain with its double cliffs (continued though concealed under the forest-drapery thrown over its bosom) from the shoulder, bare of trees but not of verdure, until this new road came. The shoulder, if we can tell from its aspect, is formed of the backs of Urgonian beds, here retaining the full continuity of fold which the dotted lines suggested on the front; but as our position gives us no advantage for observing the modelling, it will be better to examine it from another point of view.

Plate X. is an anatomical diagram of the Breson as it might be seen from a balloon a little above La Roche, and with the lower slopes of the Couz cleared out of the way. The summit in either view is the same, and the overhanging cliffs (where the fountains are in the valley of the Arve) serve to mark the bearings. The Urgonian S fold is here laid bare, in continuity with the undulating beds of the mass which we include under the name of Mont Saxonnet—that is, all between Breson and Vergy. There is the break upon the front, easily

identified with the first view, and the unbroken loop on the shoulder. Of course in nature this loop does not overhang, but in the analysis a good deal of superficial *débris* has been dissected away, and some shattering of the beds restored. Why the shoulder should keep what the front loses is difficult to tell; but folded Urgonian is everywhere most capricious in its choice of continuity or disruption. In several other instances different points along the same fold have shown different degrees of cohesion. Even without original bursting of the loop at the summit, it would be there exposed to greater violence of weathering; and after all the loop of the shoulder is not so massively continuous as the diagram shows it for the sake of clearness.

The highest layer of the Breson lies well back from the River Borne, leaving a little steep dell behind the ridge, just over the chapel. As the soft Neocomian must always waste away, leaving the Urgonian above it unsupported, and below it uncovered, this configuration is just what it would naturally arrive at,—given some enormous cleft to begin with, sketching out the valley of the Borne, and some continual power of water and ice to carry away the fragments as they fell. Imagine the strata first folded into the S, like a long roly-poly pudding from Bonneville to Annecy,—the north end then

hung over the edge of the dish (to get the dip to N. E.), then sliced through into gigantic slices, and left alone. The Neocomian, like the jam, would slip out, leaving holes under the Urgonian, like the paste—now considerably hardened, ready to disintegrate, and readily falling where unsupported. Imagine a stream or a glacier flowing through the cleft, conveniently carrying away the *débris;* and you imagine a set of circumstances which certainly would produce exactly the form we now see in the Breson.

It is separated from its neighbours on the south-west by the deep Gorge des Evaux, through which a new road gives the opportunity of taking a careful section, shown on both sides (Plates X. and XI.) The Urgonian beds are here of a creamy grey, inclining to buff; the lower one as full as it can hold of fossils; and all about La Roche lie blocks broken from it, built into walls, where the weathering has brought their shells into relief, like delicate sculpture. The Flysch is a black sandstone in beds not more than a foot thick, much broken and cleaved, and separated by finely divided shale.

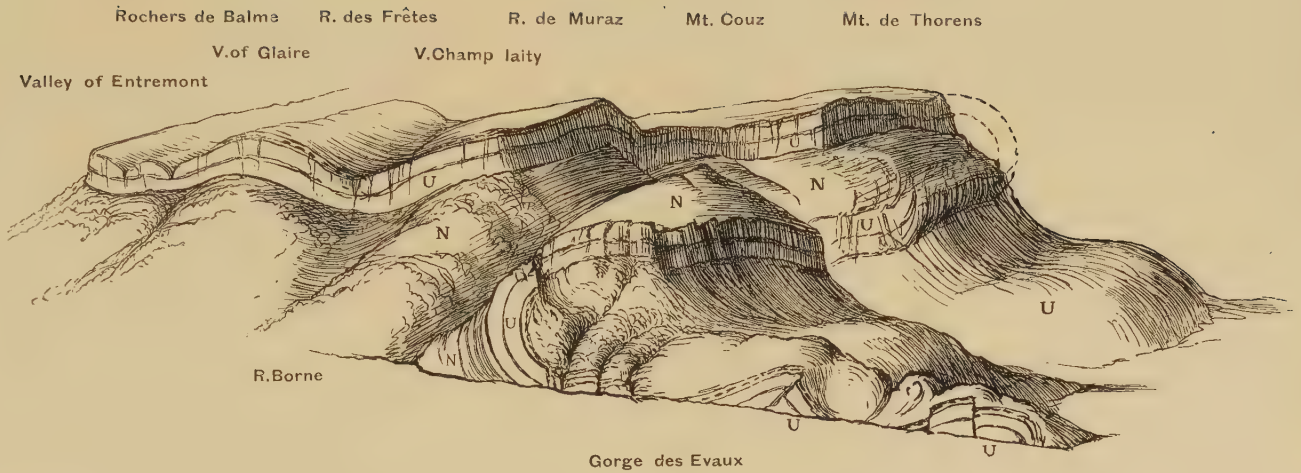
In the lower "roll," towards Bonneville, the cornice already mentioned is seen, half-way up and along that feature of the mountain. It seems to be a continuation of a fault which makes important breaks

on both sides the gorge, and which is a crack in the strata owing to strain of bending. Other important faults occur at the chapel of Notre Dame, and near the entrance of the gorge.

Notice, too, this cleavage of the Urgonian : some few lines are perpendicular to the bed ; but two sets of planes which can be seen from La Roche, by no means can be accounted for as conditions of jointing, or cleavage created under pressure. And under the summit, above the chapel, are appearances which I have tried to suggest, and attribute to the influence of cleavage, seen in perspective.

The Montagne de Couz.

On the south-west side of the Gorge des Evaux comes the Montagne de Couz (Plate XI.), known by its conical top. This is formed exactly in the same way as the Breson, only that the uppermost layer of Urgonian is not here present, though it is seen just behind the Couz in the Rochers de Muraz, and just beyond in the Montagne de Thorens. The absence of this fold may easily be owing to great breaks in folding ; for there were no superincumbent masses to hold it down ; and the result, as in the Breson, would be the weathering away of the softer Neocomian wherever unprotected. Thus a valley has been formed by the erosion of



XI. – ANALYSIS OF THE MONTAGNE DE COUZ AND OF THE MOUNTAINS BETWEEN THORENS AND THE R. BORNE.

as much as was not covered by the R. de Muraz or supported by the middle fold of the Couz. The M. de Thorens, further on, has retained the top layer, and so resembles the Breson in everything but its imposing isolation.

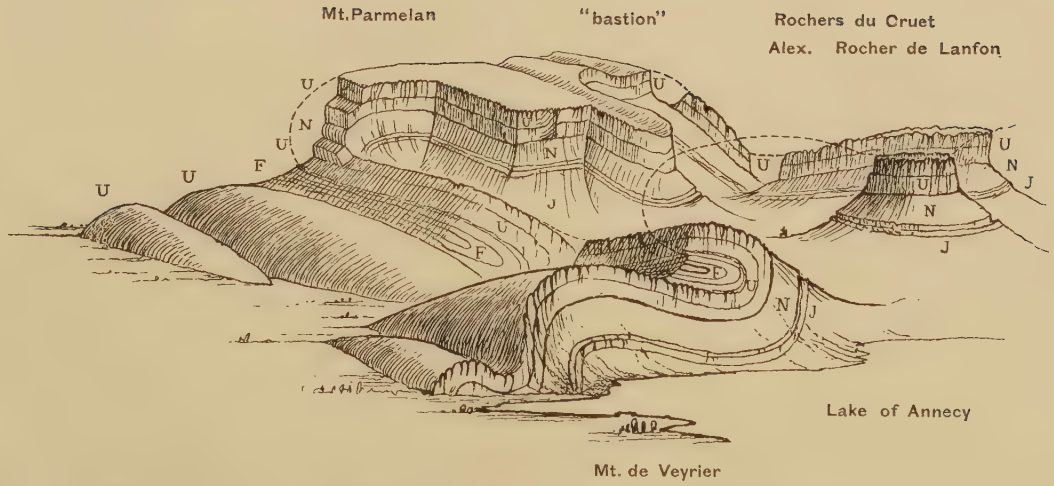
Behind the Couz, as behind the Breson, the Urgonian is crumpled up into long folds, whose continuity is interrupted only by the valleys sliced at intervals across them. The valley of Champlaity lies between the Rochers de Muraz and the Rochers des Frêtes (ending in the Crêt de Leba and Montanvert, just over the village of Petit Bornand); it rises to a *col*, or *hause* as they say in Cumberland, and then runs down to the Verrerie, old glass-works in the cross-valley of the Fillière above the village of Thônens. Just opposite this, but rather pushed westward by the dislocation originating in Mt. Venesin and marked by the Fillière, the dell of Nerval runs down to meet it from behind the "bastion" of the Parmelan (Plate XII.)

The valley of Glaire is really a double trough, divided by Mt. Achenaz and its unimportant prolongation; a line, as we have seen, continuous with the west ridge of the Cruet of Annecy lake. And on the extreme left is seen the ridge of the Rochers de Balme, ending the mass, as far as

actual cohesion goes; but connected in ideal and structural continuity with the Traversière, as shown in Plate XIII.

And below the Couz, the disturbance of the strata dies out in two or three ebbing waves, mostly hidden below the Molasse, which is piled in small hills against the flanks of the Alps. The whole of the Couz formations,—though accurately fitting on to those of the Breson, on the map,—are at a lower level, and so the "lap," or roll, gets lost here, half buried in Molasse. But still the natural section of the Gorge des Evaux shows the identity of its structure on both sides, and consequent identity in detail of the two mountains.

It is interesting to notice in the Gorge des Evaux how faults in the hard stone have started water-courses, and these have induced the erosion of the softer soils into little gullies; while the great gorge itself, though accentuated by fluvial erosion, is not the creation of the river, which simply finds its way out through the rift in the trough of the synclinal fold whose lips here approach one another; though further among the mountains, towards the Bornands, where the upheaval is more powerful and the rent deeper, the crumbling away of exposed substrata has thrown back the Urgonian layer.



XII.– ANALYSIS OF THE PARMELAN, THE MONTAGNE DE VEYRIER, THE ROCHERS DE LANFON AND CRUET

The Parmelan and Mt. de Veyrier.

The third group on the way from Bonneville to Annecy is that formed by the Parmelan and the Montagne de Veyrier; named from the village at its foot, on the lake of Annecy, and diagrammatically sketched in Plate XII. Here again the same fold presents itself—interrupted, however, not now by a sliced-out valley, but by a synclinal trough. And much more of the uppermost layer of Urgonian has come away; one great piece between the Parmelan bastion, which overlooks Alex, and the ridge which runs down to the Gorge of Dingy,—forming a valley similar in every condition to the dell behind the ridge of the Chapel of Nôtre Dame, on the Breson, noticed above: and another great piece from the Rochers de Lanfon to the backbone of the Veyrier where the great fault originated by the "Wedge" in the southern district (Bauges) is deflected and finally dies out; marking, however, the site of considerable disruption (*cf.* p. 62).

The result of the first loss is the erosion of all that valley in the Neocomian which runs up from Dingy into the Parmelan; and in the second case, the same formation has been cleared away, so as to leave bare the under surfaces of the Urgonian beds for a space along the ridge of the Veyrier towards Alex.

This disappearance of the top layer of the fold, first seen in the Mt. du Couz, is more marked towards the south, and on the shore of the lake of Annecy only the isolated Lanfon and Cruet remain to match the great coverlet spread over the Parmelan and Thorens masses.

The Neocomian beds are visible enough everywhere, to bear out this exposition of the intent of the Urgonian. On the front of the M. de Veyrier they appear curving over to the west, as drawn in the sketch, and under them on the shore, Oxfordian. In the pedestal of the R. de Lanfon they are seen tolerably level, and so throughout the body of the Parmelan.

The hollow down the back of the Veyrier, well known by the name of the Col de Rampon, is partly filled with gault, nummulitic stone, and flysch, which must have been deposited earlier than the folding of the whole. And in the next hollow, more to the west, the nummulitic beds show again with great distinctness, forming indeed the surface of the little hill caused by the last waves of the great fold.

This little hill is hardly seen in nature, being banked up and half buried in molasse; but is continuous with the last and lowest fold shown in Plates X. and XI., on either side the entrance

to the Gorge des Evaux. So that our long roly-poly pudding, after being folded into an S, must be given just one fold more, before it is quite ready to be sliced.

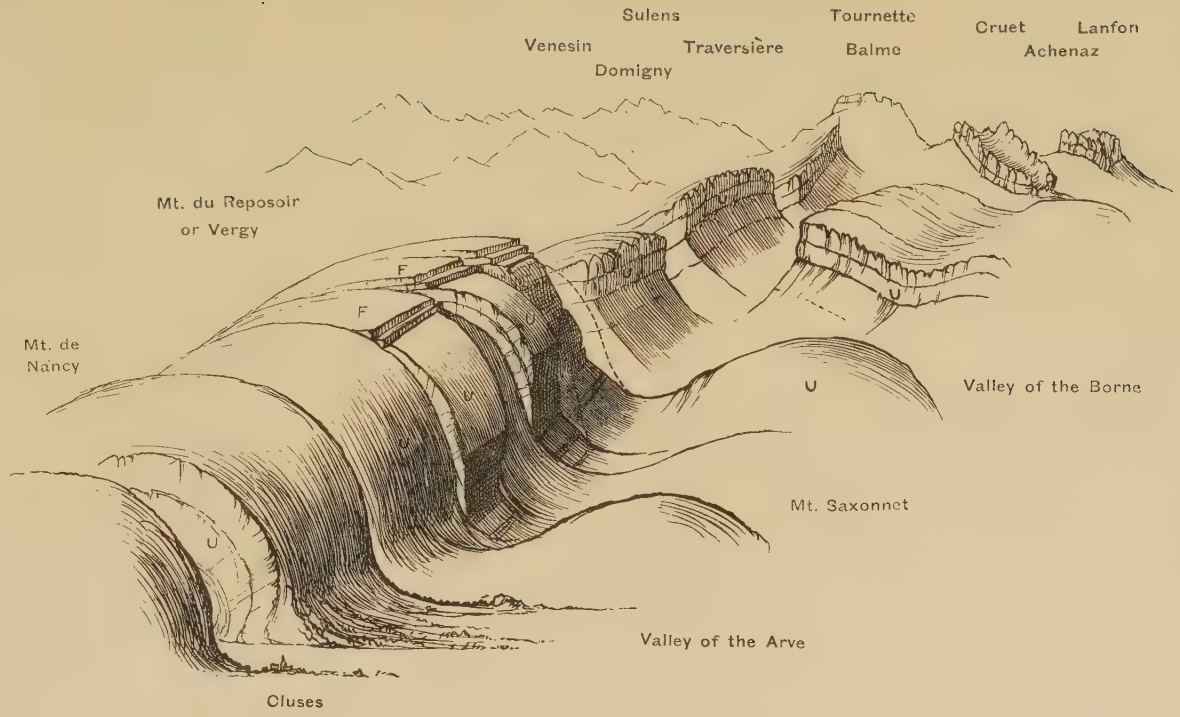
It must be reaffirmed, and borne in mind with a view to future discussion, that not only is the roll sliced or split across, but each of its thick pieces has been hoisted up in the middle. The Gorge des Evaux,—this Gorge of Dingy between Parmelan and Veyrier,—and that above Thorens, called the valley of the Verrerie, are all in a degree synclinal, but all ravines no less. This more detailed examination confirms the general idea,—that they are crooked rents, not mere eroded channels; for their opposite sides, though similar in section, do not quite coincide on the plan. Nor are they mere cuts through a level tableland, for the beds always dip to their axis of depression; as for instance to the Gorge of Dingy, obviously; to the higher part of the valley less continuously, but the "Bastion" of Parmelan, the Cruet and Achenaz (detailed in Plate XV.) all suggest an original convergence to an original chasm, whose walls have been broken off bit by bit, backwards and backwards to their present position. So that the whole range from the lake of Annecy to the valley of Bonneville could have been formed by

three sets of causes;—first, the folding into wave-rollers and a certain amount of crumbling at the creases; secondly, cross-elevation and splitting by the "wedges"; thirdly, gradual erosion and weathering, conditioned by the various relative positions of harder and softer rock.

The Range of the Reposoir.

In Plate XIII. is given an ideal view, looking south-west, of the ranges between this great western breaker and the "wedge." In the foreground lies Cluses, with a corner of the cylindrical hill above it; which did it appear in full, would show a contrast of completed and broken fold, resembling that in the shoulder of the Breson (Plate X.), or in the Mt. Vergy, soon to be noticed. Behind this is seen the Gorge of Cluses, leading to Sallenches, and the mountain on which stands the village of Nancy; with curved beds and oblique cleavage thrown into relief by a recent cutting.

The valley in which lies the monastery of the Reposoir is indicated by a break between the Mt. de Nancy and the larger roll behind it,—the Mt. Vergy, which shares with les Almes (not in the sketch) the title of the mountains of the Reposoir. Of all the Savoy limestone Alps Mt. Vergy is the most tremendous for the terror of its unsupported



XIII.—ANALYSIS OF THE RANGE OF THE REPOSOIR.

precipices, and most mysterious in the smooth scales that roof its back, like adamantine armour of leviathan, prone upon the shore. The sketch shows nothing of this, but suggests their structure in the overlapping beds of Flysch and Urgonian, broken in the bending. Half way along, apparently burst by the upthrust of the cross-axis of elevation from the wedge, the whole thickness of Urgonian has crumbled away, leaving a smoother slope of Neocomian, which affords a perilous stairway to a pass across the range. Not far behind, the continuity of the fold is again broken, and the vault of the Vergy gives place to the mere ridges of Jalouvre and Domigny, above the valley of the River Borne. These are the transition to a different condition of the same wave-line (as we have already ascertained) in the Traversière and ridge of the Balme: in which the wave is not so compressed, not so arched, not so complete; the "wedge" in Mt. Planay, as we saw (p. 37) presses the Dorans chain, but leans less heavily on Domigny. And in both section and picture, the Vergy looks as if it had been crushed in from the side; the Traversière-Balme range seems to have been heaved up from beneath, and burst lengthwise without such energetic arching of the beds. And in the distance is the Tournette, with the Rochers du Cruet,

seen in a new view, carrying on the lines of the Balme and Achenaz.

On the side of the Vergy is indicated a cleavage parallel to that seen on both walls of the Gorge of Cluses, and which is so strongly marked as to quite assume the appearance of bedding. Indeed, so unparalleled in ordinary experience is the vaulted structure on this huge scale, and so appalling to contemplate both in its cause and its consequences, that it would be almost a relief to the imagination if one dared believe that Mt. Vergy was built and sculptured as other mountains are, and its courses laid in more mundane method, Titanic though the masonry should be.

§ 3. CLEAVAGES.

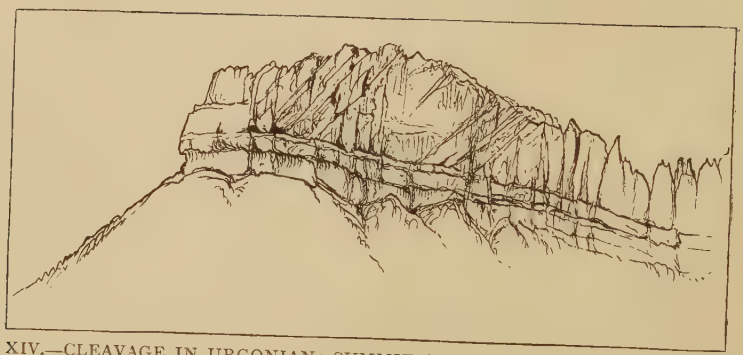
The whole of our examination of these mountains and valleys centres upon the arrangement of their beds. From considerations at once geographical and geological we hope to discover the true structure of the district, and to throw some light upon the circumstances, and perhaps the causes, of its creation. This discovery is only to be made by putting together a multitude of independent observations of the strike and dip of rock-surfaces and crevices; and the opportunities for such observations are always rare, and often most misleading.

Indeed, even those observers whose experience might be supposed to guarantee them from mistakes, have been continually misled by strongly marked cleavages, which assume all the appearance of bedding, and lead to unsatisfactory conclusions about the internal structure.

It might be supposed that in a country formed of such a well-defined and distinctly sequent series as these limestones, there could be little difficulty in disentangling the intricacies of cleavage and bed. But, though it is a land of rocks, the rock-surface available for observation is comparatively very limited ; and accidents of landslip, circumstances of overgrowth by vegetation, concealment or disguise by water and snow, invalidate many well-meant observations. Examples of such difficulty occur to anyone who has noticed the chaotic crags of the Mont Vergy (Reposoir) ; or who has passed along the new road of the Gorge des Evaux, between Bonneville and the Bornands ; or remarked the rocks by the roadside near Talloires on the lake of Annecy. There is only one criterion to determine the structure of such neighbourhoods,—to consider them as details in a great whole, of which one has taken the trouble to grasp the general structure ; not as seen in a map, nor in a picture, but in three dimensions, as given by a model.

Meanwhile, the examination of local structure will be greatly helped by a clear understanding of what is possible to these limestones in the way of cleavage. An exhaustive analysis of the subject is not attempted; we can only arrange a few examples under their different headings.

The simplest cross-cleavage that everyone knows and notices is simply the splitting of rock across the bed, at right angles to the plane of bedding. Sometimes the influences which create the cleavage have been more important than those which left the bedding visible; and here is the first risk of mistake. But in our English flags and slates of the Lake country—in the Coniston limestone, and even in the volcanic ash and felstone, we can trace other sets of planes, at right angles to one another, but at acute angles to the bedding and cross-cleavage; these sometimes attain a misleading importance. For example, the cleavage which makes both Coniston clay-slate and Coniston green-slate, has the same strike with the beds, but a different dip, and sometimes entirely effaces all trace of the beds. So in Savoy limestone we can trace, beside the beds and primary cross-cleavage, secondary planes, exactly resembling those of crystallization. See, for instance, the analysis of the Breson (Plate X.), and the sketch of the



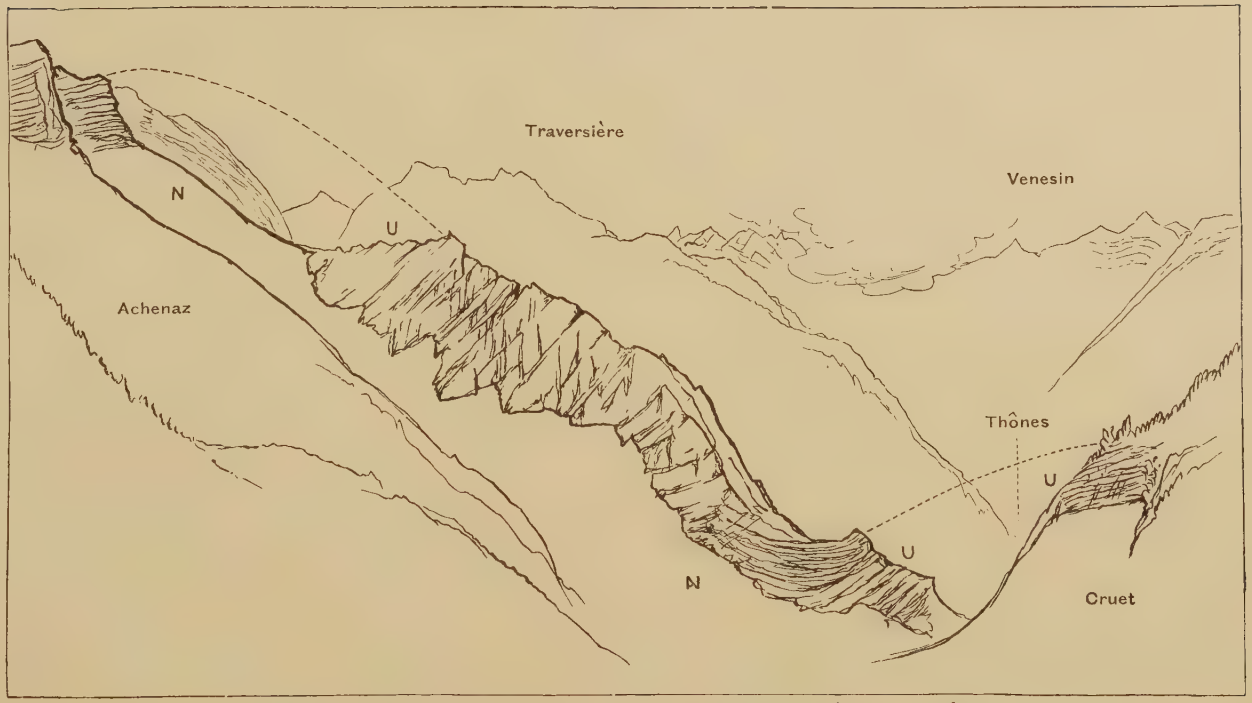
XIV.—CLEAVAGE IN URGONIAN; SUMMIT OF THE ROCHERS DU CRUET, FROM ALEX.

Rochers du Cruet (Plate XIV.). In the first instance are strong lines crossing the beds at acute angles, creating fissures and crannies ; in the second, we see the bedding of the Urgonian strongly marked by the double line which always divides the whole formation ; also a vertical splitting of no importance as a cleavage ; and across these an oblique cleavage, distinctly marked,—at least in snow-time ; and making the whole mountain look like one great crystal. I have also a drawing, not engraved in this book, of the Rochers de Lanfon from Alex, with all the tops bevelled by a crystalline-looking cleavage-plane, as though the Urgonian were so much calcite. And passing along the valley of Cluses, it will be seen that the Oxfordian is characterised by a cleavage dipping at an angle of 50° or 60° west ; the Neocomian, strongly furrowed by a cleavage, about 45° east, which every now and then asserts itself in deep clefts, and on the Aiguille Varens determines the shaping of the mountain mass in its middle wooded and grassy flanks, all of which are Neocomian, and bevelled by these cleavage-planes.

From this it seems that cleavage of limestone need not be perpendicular to the bedding; and as the lateral thrust that crumpled up the beds into their present position was in the direction of their

planes, it is evident that many of the cleavages are not perpendicular to the line of the only considerable pressure which was likely to have produced them,—if they could be produced by pressure, as is commonly believed. For the origin of cleavage we must look to some other causes than mere pressure; and, as their effects resemble those of crystallization,—*are* crystallization indeed on a large scale,—are seen to be so on a model of the mountains in which they are marked, we can only refer like ends to like means—metamorphic action, or whatever these means may be thought to be.

In the second place, many cleavages are not constant in their relation to the beds. Those of the Oxfordian and Neocomian, in the Valley of Cluses, seem to dip at the same angle to the horizon, whatever be the tilt, or even contortion, of the beds; and at the Nant d'Arpenaz, a cascade which falls over a great fold in the Oxfordian bared in natural section, can be traced the same cleavage dipping west, and steadily crossing the twisted beds. That is to say, that not only did the pressure which contorted the strata fail to produce this cleavage (what it did produce we shall soon enquire), but this cleavage seems to have been created after the contortion, by causes of a quite different nature.



XV.—CLEAVAGES IN URGONIAN; FROM ALEX IN THE VALLEY OF THÔNES.

The pressure in the direction of the beds did have an effect,—in cracking them across into joints, which are more strongly marked where the contortion is more violent. At the Nant d'Arpenaz this jointing is plain to see, but differs from cleavage in an important respect. Cleavage runs through the whole formation; jointing only breaks each layer or little bed at its own weakest point, without extending the crack in a straight plane throughout the mass. The Flysch at the Gorge des Evaux shows this remarkably. It is violently disturbed, which breaks it into joints, across the beds; but these are not cleavage,—which can be traced independently. The jointing is local; and is produced by mechanical pressure and strain, most marked where the strain is strongest.

Cleavage, too, can be local; sometimes produced, like jointing, by strains; in which case the two sorts of results show only small differences —sometimes crystalline, and sometimes developed in land-slips, which afford very important phenomena.

Cleavage from local strains is illustrated in the sketch of the spur of Mt. Achenaz, the northern continuation of the Cruet in the valley of Thônes (Plate XV.) Here the already ridged waves of Urgonian seem to have been violently dragged

apart, burst asunder at the "cluse," or chasm, forming the middle of the valley, and all up either bank flawed and fissured by such rents as are made when a lump of nearly dry clay or paste is dragged in two. The same appearances are seen at the gate of the valley of La Verrerie, over Thorens, where the spur of the mountain of Thorens seems to have been dragged away from the Parmelan. In the Parmelan, as seen from Alex, is a sudden break, where the Urgonian seems to have been folded upwards and snapped off; though, apart from this shattered or cloven appearance in the natural section, there is no reason whatever to believe that the beds have been specially disturbed just there, lying, as they do, elevated, but level; uniform in thickness, and unbroken in extent.

Again, metamorphic action, or some crystallizing cause, creates occasional crystalline cleavage. In quarries and cuttings in the Oxfordian, about a mile east of Talloires along the road, are cleavages which have all the features of bedding; being rough, continuous fissures, while the true beds, only known when the surrounding country has been studied out, are less notable lines sloping down into the lake. Indeed, all the formations are in some places more energetically than

elsewhere cleaved in crystalline planes. It is not usual to see in Urgonian the notable cleavages of the Lanfon and Cruet* (Plate XIV.), nor is it common to see Flysch cleaved like slate, as on the Rocher de Cheire, towards the top of the eastern wall, over Talloires. The full discussion of this subject is beyond our reach; but the fact can be established that there is a cleavage to all appearance crystalline, and that this is more developed in some places than in others.

The third case of local cleavage is where portions of beds, slipping down a slope, do not shatter, but split; emphasizing perhaps already suggested planes of cleavage. Above Eugene Sue's old house at the foot of Annecy lake, large fragments of the Montagne de Veyrier's wrapper of Urgonian are splitting off and sliding down the Neocomian slopes. Such a form may occur wherever the normal wall and slope of Savoy is found, and that is almost anywhere; although generally the blocks that split away are not massive enough to grip the ground, but roll to the valley or plain.

The most important example of such a kind

* And yet many extended spaces and faces of this formation show some cleavage, especially when the sun or the season aid the observer. Possibly these, if properly examined, might reveal systematic interconnection.

is the well-known problem of the buttresses of the Salève. From the Geneva side we see the Neocomian summit, with its triple cornice, surmounting a wall of Oxfordian, against which rest, here and there, stacks of Neocomian or "Valangian" (its lowest beds), exactly resembling buttresses of a Gothic church. The face of the Salève is horizontally marked by the outcrop of the gently rising beds; but the buttresses are strongly lined with vertical fissures, about which great disputes have arisen; many writers considering these fissures as bedding, and the buttresses as remnants of the burst Neocomian, which had been strained over the squeezed-up Oxfordian wave, and cracked along the axis of the anticlinal, so that the under crust appears only slightly covered by the steeply sloping upper crust. Professor Ruskin has shown reasons for considering these fractures as a vertical, accidental cleavage of masses slipped down from above or dragged up from below, at the creation of the great fault which makes this great façade (*The Geologist*, 1863, VI. 257; *Geological Magazine*, 1865, II. 52). The buttresses are not in a normal position; as a segment of the vault, they would be only slightly inclined. They must have been either pulled down or dragged up; and could hardly fall intact into so different a position from

their original one. But such action would start and enlarge already existing cross-cleavages.

These examples will be sufficient to illustrate the complication of this branch of our subject, and to emphasize the distinction between jointing and crystalline planes, general and local cleavage, and the results of occasional fracture, metamorphic action, and concussion.

Postscript to Chapter III.

It was only after completion of the foregoing remarks that Professor Alphonse Favre's works were put into my hands. The object of his *Recherches Géologiques* has been exhaustively to survey and describe in detail those appearances of nature which I have sought to grasp as a whole, and to give in rough generalization. They embrace, with much country beyond my range, the northern part of my district, which I name after the old duchy of Genevois. In much eagerness, and more fear, I compared his masterpiece with my school sketch from the same model; and discovering that in general I have not misrepresented the facts which he has so ably and so minutely investigated, I leave my own work as it was; choosing rather to point out my mistakes than to tacitly correct them. Mistakes, no doubt, they must be; for Professor Favre, besides being an authority on geology, is an authority on Savoy,—has mapped the country both topographically

and stratigraphically; and a very slight acquaintance with the subject and his treatment of it is enough to inspire the greatest respect for the accuracy of his observation and the justice of his reasoning.

Then, to confess my errors! In the first place, Professor Favre draws his Tournette with a single thickness of Urgonian,—no fold, but a sharp V-shaped synclinal dip between the Tournette-top and the Cruet. Mine, I confess, was based merely upon sketches of the general appearance of the mountain, and not on a close survey or patient perambulation of its soil. But I have carefully studied the Tournette from the Roches de Cheire; I know its general aspect from all the Annecy side in time of snow, when the rocks show plainly, as they do not in summer. There is certainly an appearance, possibly an illusion, of a twist or fold, and a doubling or even trebling of the beds. Indeed, if they be doubled, they must be trebled, for the Urgonian of the summit is not upside-down; and topped with grit, like the Breson, not with reversed Neocomian, like the Couz. Also from the opposite side, from Thônes, the same twist could be traced, as I thought, in the curving lines to the right hand of the mass, drawings of which I have made, but with much other such material, neither described nor engraved.

And yet there is no trace of a twist in this line along the cross sections of the district, and Professor Favre's drawing maintains a continuity of structure which is capitally characteristic of these Alps. Only, it is not impossible for part of a vaulted ridge to topple over into a fold, especially under a lateral pressure stronger than ordinary, as is here the case owing to the broader and higher thrust of the "wedge" in Mont Sulens. The

Reposoir mountain (Vergy) shows a vault, very nearly become a fold; a little more of a push from the Almes, and the Breson or my Tournette would be imitated.

The coal-mines of Montmin or Marclosan, lying in a synclinal ridge, which forms the southern spur of the Tournette toward Faverges, are understood by M. Favre to be continuous with the V-shaped dip. I had supposed them to represent the lowest fold of my Urgonian slightly more curved, and freed of the upper layers which are left only on the highest part of this mountain.

Again, my drawing of the Montagne de Veyrier shows a strong twist, where Professor Favre's only dips into a trifling synclinal trough at the Col de Rampon,—that notch in the crest above the village of Veyrier. The view of the mountain in question, from over the lake, shows a most notorious appearance of actual folding, more than mere undulation; and, as to the back of it, from Alex one sees slopes of Urgonian having the fluted and scaled appearance of bed-backs, rising to the long crest which forms the eastern wall of the Col de Rampon. Indeed, in his Fig. 8, Pl. XI., M. Favre gives a section of this trough not unlike my conception of it, and whose reconciliation with his Fig. 1, on the same Plate, is not easily apparent.

In the Parmelan he does not suggest so much of a twist as I have given. I take the curving lines above the Gorge of Dingy—drawn in the analysis (Plate XII.), with very slight conventionalization, as they really appear from Annecy le vieux—to be the sloping section of a fold in continuity with that of the Breson and the Couz; but from M. Favre's analysis an adequate explanation of this curious appearance can hardly be gathered.

Mount Venesin (or Vaunessin), which I have not been

able closely to examine, I have drawn domed, from analogy of the neighbouring heights, by which I concluded that it was merely a state of the "wedge," which here had not thrust lower formations to the surface. If, however, M. Favre is right as to the dip of the beds of Flysch (often very difficult to distinguish from cleavages), here is a most remarkable sudden development of this generally subordinate formation. A similar phenomenon is more than once suggested by Professor Studer, in his section of Savoy (*Geologie der Schweiz*, etc.), where he makes whole Alps of Flysch. But in this case, by M. Favre's own showing (Fig. 1, Pl. X.), the beds are domed as I have drawn them in the Venesin, only a short way to the north of it, in Mont Maisy, a little ridge connecting Venesin with Mont Planay, and here his Flysch thins down to a trifle.

In other respects, my sections are not far out,—not much to my credit, perhaps, as he recommends this district to young beginners, on account of its definite character and simple divisions. But I have been everywhere more definite and simple than perhaps the subject allows; and trying for diagrams rather than details, have left my cross section No. 1 a very inadequate rendering, hardly an adequate suggestion, of the complexities of the Mole and the Voirons. In a broken country, crossed and recrossed by faults, like this province to north of the Arve, one of the chief difficulties in section-making is the choice of good typical leading lines; for parallel sections taken ever so carefully at regular intervals give no more notion of the structure of the whole than they would of a cottager's apple-pasty. The only sufficient rendering would be a thorough geological model.

The southern part of my district, the Bauges, is not included in M. Favre's survey. The general cross-section has been given by both M. de Mortillet and M. Pillet, but without serious discrepancies between one another, and the sketches here offered. To M. de Mortillet I owe the sketch of the formations (chap. I. § 3).

There are also sections of Savoy in Professor Studer's great work on the geology of the Alps; but slight and apparently unstudied in details.

PART II

HISTORY.

CHAPTER IV.

ARCHITECTURE OF THE ALPS.

§ 1. THE GEOLOGICAL PERIODS.

THERE was a time when this great sea of stone, now so tossed and tempestuous, was calm. Before the storm broke, its quiet surface rose and fell only with the cyclic tides which heaved or lowered all Central Europe slowly and simultaneously. Up hill and down dale; across chasms, along ridges; from point to point, or in wholly unbroken line, can be traced the great limestone beds; and by consideration of their limits, and the circumstances necessary to produce such sheets of stone, it can be judged of the time and manner of their deposition. And very slowly it was that these coverlets were spread over the fire-forces sleeping beneath; quietly the courses of this masonry were laid in the temple of the Alps, so that no axe nor hammer was heard in all the building of it. And when the full time was come,

a steady, resistless power upheaved the strata ten thousand feet, and left them there, towered and domed and turreted.

The history of our Alps begins with the deposition of their earliest formations. In the time when the Lias was formed, our district was only the bottom of a tropical ocean, swarming with shell-fish now extinct,—great coils of gleaming pearl or glowing bronze floating through green translucency of sultry seas. What cliffs or shores were beaten down to form the fathoms of cretaceous mud which gradually settled over the earlier sandy sea-bed, we cannot judge from the limits of our present research,—nor indeed does it matter; for why, as this is no cosmogony, should we not be content to begin "*ab ovo*," without asking the interminable question, "Who *laid* the egg?" The Lias fossils are the shells of creatures who lived in a great tropical sea; and only under those conditions could its beds have been deposited, whencesoever their materials were derived.

But after a while the sea grew shallower, and part of the bottom emerged—nearly all we now call Savoy—as a slimy mudbank; soon overshaded by palms, and tenanted by reptiles, like some swamp of the Amazon or the Congo. On its beach, now the Salève and the western hill-ranges

of Savoy, beat the sea, little changed as to climate, and depositing with its limy mud—now hardened to Bath and Kelloway stone—fragments of ammonites, and the fauna and flora of the tropical island, broken by the breakers on its shore.

The land was then slightly depressed; and in the shallows thus created, sponges with other strange sea-creatures lived, and left their remains in the lowest beds of the Oxfordian. And this subsidence continuing at the same time that rapid and ready supplies of ooze were being formed, the hundred yards of Oxford clay were laid down in a sea where few large creatures lived; where at any rate few such died; though, when the formation was nearly complete, and much less rapidly deposited, there was space enough for sea-urchins to float there; and in the last deposits of sandy dolomite can be traced the presence of huge saurians in fast-drying shallows.

Once more the land rose, and the water fell, leaving Savoy again dry land or fen; and along the old sea-coast, from the present position of the Salève to the M. du Chat, coral-polyps raised their reef so busily that now they form thick banks known by their name.

Now the sea gained slightly on the land; depositing Portland stone, with here and there a huge

shell in it; and to north, the Kimmeridge, crowded with the remains of lovely little shells, whose dog-Latin titles provoke interpretation; the Nut Venus, the Doubled-under Mussel, the Solitary Oyster, the Bored Bench, and the Inconstant Beak!

Now the sea drowned the land, except perhaps part of the Chablais, and set seriously to work to deposit the Neocomian, in which it was helped by shell-things and fish—but notably at first by the Big-winged Oyster—and then by the Flattened Star-shell (*Ostrea macroptera* and *Toxaster complanatus*), characteristic of its lower and upper beds.

And having formed these ponderous banks, the Savoy sea set to work again to lay down the Urgonian. Whence all the mud came, who can tell? from tottering cliffs long since fallen? from some Atlantis or Lyonnesse long washed away and drowned? from countless millions of minutest organisms such as now form the Atlantic ooze? The process of depositing new matter still goes forward, as every river carries its tribute to the sea; but in an age of more frequent upheavals, and more reckless cracking and splintering of lately upheaved peaks, *débris* could be manufactured on a much grander scale than among our punier crags,

long since reduced to a very safe and stable equilibrium. In this sea, as it then was, the characteristic creatures were the Rudistes, from whose abundance the formation is called by German geologists Rudistenkalk.

Finding new material for deposit, the sea, still swarming with Urgonian fauna, formed the Gault; ebbing from its shores, till, as only a narrow gulf where now are our Chambéry and Annecy Alps, it deposited the Chalk.

But now threatenings of a new order of things began to be felt. Not turbulently, though irresistibly, some district of limestone, probably that where the Central Alps now are, was raised and broken up; whose ruin, washed into a narrow sea (coincident with the cretaceous Alps of Savoy), and added to shoals of circular shells and weed-forests, made the Nummulite beds and lignite layers.

It is a very old story, this of the great Revolution; for if the Gods of the Greeks are but nature-powers allegorized, what are the myths of the Titans and the Giants but the world's history, intuitively grasped and epigrammatically told? There are few truths about the physical being of nature and of man that early Greek philosophy has not touched, —tentatively, perhaps, and without method of posi-

tive verification, but brilliantly and suggestively; and here, too, their poets seem to have told a true myth.

They sing how the primeval fire-forces and wild water-floods which ruled the nascent world were supplanted by new dynasties; till Zeus, Hades, Poseidon—*our* air, earth, and water—overpowered and imprisoned their turbulent predecessors, the Titans; as the milder influences of the secondary ages overcame the earlier chaotic state of things, and shaped the world into seas and soils capable of nourishing life. But the buried giants, their kin, rebelled, and piled the hills to scale the heavens. Then it was, as the Greek myth would put it, that Mont Blanc heard the cry of battle; reared himself from the depths where he had been imprisoned under the great coverlet of snowy stone which Hades and Poseidon had in vain spread over him; reached out his arms to shatter into ruin the roof of his dungeon; while all his lesser brethren rose around him, till the cataclysm of the universe seemed imminent. But his force was not what it had been, and air and water quenched his fire. He quailed under the blue eye of Athena, the child of Zeus, and withered beneath the darts of Apollo. Hermes cast over him clouds and snow; Hades, the "hider," made earth more solid above

his head; and upon him, shattered in his turn into shivering ruin, Bacchus laid the tender, tenacious grasp of his vine-tendrils.

That was their dream of creation, and here is the interpretation of it.

At what time appeared the present central chair of Alps may be disputed; but it was before the sea had left Savoy, and while the Flysch was being deposited in it; whose earlier beds contain little, but its later much, quartz and mica (got from none of the limestone layers) and granite that could only come from Mont Blanc. During these times, too, the creatures of the sea seem to have felt the not very distant disturbance; and of multitudes formerly teeming there, only a few fish were left to swim about in tangled weed, left from an earlier age's forests; and as the banks emerged on the sides of budding Alps, sea-worms left their tracks in the soft mud.

However, till the true Flysch was finished, none of the upheavals and contortions of our Savoy mountains took place, for in all these it played its part; and when the Urgonian is folded, the Flysch is folded too, like butter on the bread you double up. See for an instance of this the Montagne de Veyrier (Plate XII.) But as true Flysch is sometimes so like its successor, Molasse (*e.g.* at

the base of the Voirons), that even the accurate and painstaking compilers of geological maps have confused them, it appears that the great upheavals of the Alpine Revolution took place at a time when other terrestrial things were going on orderly enough; and hardly altered the character of the rock deposition as then going on, except that the water was thrown westward, and a larger variety of *débris* supplied to it.

The Revolution threshed to chaff the level limestone layers, and the waters winnowed them. Where the Nummulite sea had been—over our district—level strata were lifted aloft, crushed together, folded over, rent and torn, and their broken bits thrown and washed down to the chasms and the plains. The elevation of the land threw off the sea; and every outlet to the west being barred by the Jura, for a time the lowland from Bâle to Bourget became a lake, at whose bottom formed the freshwater Molasse, made out of this *débris*, with such palms as had grown on the shores of the Nummulitic sea now turned to coal-beds in the Molasse, added to shells which adapted themselves to a fresh-water existence.

Then the Rhone found its course—till then not cloven, or else choked by rubbish of the upheavals: the lake was lowered, the sea of France joined

it and converted its straitened space into an inland gulf, very restricted in Savoy, more spread in Switzerland. The sand and pebbles of its bottom, bored by Pholades—worms which have their home in stones as some have in books—mixed with various marine shells, now form the Nagelflüh—Nail-floe.

But, in spite of its late appearance, the Molasse was not to remain undisturbed. Though the great revolution was past, the last struggles of its dying power were not spent, and these have left the Molasse broken into those low hills known as the Bornes, between the subalpine range of the Salève and the Alps of Annecy.

Before passing from these earlier periods—the building of the mountains—to Pleistocene times, when the valleys were formed and filled, we ought to examine in a little more detail the effects of the upheavals, and their permanent results.

§ 2. THE GEOLOGICAL REVOLUTION.

So far we have seen the formation of the greater part of the materials from which the Savoy mountains are built up. But as yet these materials are at the bottom of the sea, or, at most, slowly and gently emergent; they have not yet been

arched into even the gentle undulations of our downs or of the Côte d'Or hills along the railway line to Dijon. We cannot long entertain any idea that the convolutions which we see in them can have been produced in course of deposition, by such causes as on a smaller scale have twisted and kneaded some deposits of drift; thrusts of boulder-laden ice-rafts; irregular deposition by varying currents, charged with sometimes more, sometimes less, muddy material,—even should the gigantic hypothesis be granted of such a cosmic cataclysm as could convert all Europe into not merely a sea, but a stream,—not merely a stream, but a torrent. A glance at the Nant d'Arpenaz or the Breson is enough to convince one that throughout all the bending and folding the original beds are homogeneous and continuous. The bending of the beds took place later than their deposition, and by causes of a different nature from those already in operation.

Nor have these mountains been merely, if at all, carved out of a simply and steadily raised plateau, like the summits of our chalk downs, where we see horizontal beds cut through by valleys of erosion. In Savoy the making of the hills left the valleys; in our chalk downs the making of the valleys left the hills.

It was some great "creep" and commotion that raised these beds some thousands of feet above their original level, bent and twisted them, crushed them together into waves, and rent them asunder into great blocks, to be left to the action of frost, air and water to finish the sculpturing of masses thus roughly modelled.

The causes of such commotions are the province of speculative physicists: of their nature and effects we can learn several well-defined notions from an analysis of our knowledge of these Alps.

In the first place, the upheaval did not happen suddenly, nor all at once; it happened slowly, and extended over several periods, during which the elevation of various parts went on gradually, and by no means simultaneously nor uniformly.

That they were not wholly undisturbed—nor ever had been fixedly quiescent—has been seen from the continual elevation and depression of the land as a whole in the successive periods; and during the latest secondary age, the fact that Nummulitic limestone is partly composed of *débris* of the gault and chalk on which it rests, shows that some slight disturbance had disintegrated these; if not immediately in its neighbourhood, at least not far away. A gradual emergence of the Alpine chain would necessarily

break up a gradually increasing area of these secondary strata, whose first fragments, washed into the sea surrounding the budding island, would make the Nummulitic formation. As the Alps rose, as the gneiss and metamorphic schists appeared, and broke away or weathered under the atmosphere, the new micaceous mud and gravel would be spread far and wide over Savoy, still under the sea, or slowly emergent, though chiefly covered with salt water; and this was the Flysch, deposited sparingly over the limestones, though here and there believed by authors to accumulate to much greater depth than usual.

All the cretaceous formations are thus overlaid with beds of *débris*, not made from the same stuff which had hitherto been supplied to make the great limestones; but from fragments of rock before unknown, and now appearing for the first time (that is, during the geological periods which have just been described) in the gneissitic central range of the Alps. To admit the deposition of Flysch so evenly over the Urgonian, Gault and Nummulitic beds, tolerable quiescence of the whole Savoy district must be granted, while somewhere, and that not very far off, was rising a range of micaceous rocks, such as the great Alpine chain. It was this rising of the Alps that tilted the whole

district, and gave it a dip to westward ; the first step in the crush which threw Savoy into waves. Even this first step, as we see, took time to accomplish. So that the ridging and contortion of the district was not the work of some sudden outburst which rapidly threw up Mont Blanc and crushed up Savoy at the same time. But during the two ages of Nummulitic limestone and Flysch, some backbone of Alps was being or had been upheaved. And not only the gneiss and mica-schist appeared ; but even the granite, generally believed to be a second and later development of Alpine upheaval, leaves its *débris* in Flysch ; along with bones of fish, prints of seaweed and worm-tracks,—proving that during this first phase of the Revolution, sea or a salt lake covered the yet comparatively undisturbed limestone of Savoy. But the upheaval of the Alp chain has thus gone on during two geological ages—how many years that may mean is beyond easy computation —and still no Savoy mountains !

As two long periods were occupied in preliminaries, we should be justified in supposing that the performance of raising these limestone Alps was not more sudden. Indeed, the Revolution in Savoy was merely the extension and sequel of that begun in the Central Alps ; and we shall see that

its completion necessitates two separate eras; the first (to anticipate) of wave-making crush; the second, of gorge-making upthrust.

First comes the period when no more formations were laid upon the limestone; that is, it had risen from the sea, at last upheaved; and by the increasing development of the Alpine earth-creep, it was not only lifted but crushed—lifted on the flanks of the great Alps, and crushed laterally by the extension of the same influences which caused Mont Blanc itself and the Central Alpine axis to rise. This lateral pressure would have one direct effect, namely, to crumple up the flat layers into parallel waves, into the parallel ridges which everybody since M. Elie de Beaumont has remarked as characteristic of the secondaries.

What complexity of forces both raised the emergent Alps and created this lateral crushing of the whole limestone sheet from the Jura to the Buet is a matter of speculation. They say the contraction of the under layers of the earth's crust, as they cooled, corrugated the upper layers, and to that we owe the whole result. Some such contraction would have a double effect: on the outside and on the inside. On the outside it would corrugate the earth's surface, and the

arches or vaults so made would suck up the stuff underneath, giving a semblance of actual upthrust ; but on the inside it would so compress the still plastic matter as to make it seek some vent at the point of least resistance in the contracting coat. At such a point it would create volcanic, or at the least, elevatory action. It would not necessarily perforate the surface and eject lava, but some might escape between the contracting crust and the upper layers, causing upheaval of the latter, with great heat and possible intrusion of lower strata of igneous or highly metamorphosed rock ; all this being an entirely different process from mere corrugation of the outer crust. So that the two results of crust-contraction, working together, would both throw up a central or axial height, and also wrinkle the surface into waves, whose direction would be controlled, and whose position would be sketched by this nucleus or starting point of actual elevation, and whose material would be acted upon by the heat accompanying this quasi-eruptive elevation, as well as by the motion produced by the mechanical crumpling of upper layers affixed to a contracting base.

This is exactly the case in Savoy. We have our parallel wave-lines, which might, so far, have been the result of this general corrugation without

vertical upheaval. But there are also evidences of vertical upheaval, as though the central chain of Alps were on a line of weak spots such as have just been suggested; through which real up-thrusts took place. First, it was not one single moment, or even process, that raised the whole chain, or even the comparatively small mass of Mont Blanc, as it seems. That is to say, the central Alps are not just the sucked-up stuff under one greatest wave (like the parallel waves of the secondary Alps) subsequently denuded and degraded to its present state. Several distinct upthrusts supplemented the great general corrugation. Secondly, we have evidence of great heat nearest this Alpine axis of what seems to be vertical elevation: heat that has metamorphosed the limestones in proportion—not to their disturbance, but to their proximity to Mont Blanc. For instance, at the Perte du Rhone, a neighbourhood where the Urgonian is almost as strongly contorted as anywhere, it is milk-white, while it gradually grows darker and darker till it reaches the Dorans range, where the heat accompanying the elevation of the central chain of the Alps had metamorphosed it into a hard dark-grey stone. These facts show that there was a distinct increase of action upon even the outermost crust along the line of the central Alps.

And not only in their central upheaval; but a vertical force seems to be manifest in the creation of the "Wedge," where simple lateral pressure does not account for the sharp sudden intrusion of lower strata among the cretaceous beds, reaching a climax in the Serpentine centre of the Chablais (chapter ii., § 3). The aspect of the wedge is on a small scale like that of the Central Alps; it shows both vertical upheaval and lateral pressure. The cross-waves, which create the great east-and-west masses of Genevois and Bauges, are vertically upheaved by a series of forces imitating, in little, the series of elevation-centres which produced the Alps, and at the same time raised their flanking buttresses. And the intrusion of the wedge thrusts into more vigorous contortion and more crowded lines the already sketched ridges of the north-and-south waves of Savoy; in this respect again mocking Mont Blanc and its compeers. For whatever undulations were originated by the general corrugation might be, perhaps must be, emphasized by intrusive upthrusts which could not but exert considerable lateral pressure.

This creation of the Savoy wedges (the gorge-making upthrusts) is the second period we have premised,—easily understood if it be considered as the carrying out of the programme begun in the

preceding stages of this Revolution era. A continuation of the outburst through the same weak point at a later age would find further direct upthrust difficult when the Alps had been formed directly overhead, and would exert its force laterally beneath them, pushing away right and left till it reached a weaker zone in the roof that held it down. This weak zone would be the line along which these upthrusts of the wedge took place, immediately beyond the great mass of the Central Alps. There, acting as the first outburst acted, with vertical and lateral pressure, it would produce the appearances we have noted.

That this process is later than the formation of wave-lines and contortion seems to be proved by the present aspects of the district in section and plan, as already discussed. It is needless to recapitulate detail to show that the waves are "prior in thought" to the wedges; that they are also "prior in time" is, at least, a very probable theory.

Though these paragraphs have entered the region of hypothesis, it has been rather for the sake of suggesting a better grasp of the facts as we see them, which can be understood more easily from some hint of their possibility, than as an attempt to establish the history of so obscure a period. We have the two preliminary stages of gradual

disturbance of the ocean-bottom, and consequent formation of nummulitic beds and flysch; then the raising of the Alps as we have them, and first lateral pressure, ridging Savoy; then the elevation of the wedge, and further dislocation and crushing of our secondary Alpine ridges.

The *débris* of these later stages formed the Molasse; first deposited in a great freshwater lake between Alps and Jura; and then, as this was united to the Sea of France, in salt water. The Revolution ended in the general elevation of the middle region of Europe, freeing it altogether from the sea; leaving a great lake, whose shores were gradually narrowed by the deposition of Pleistocene soil, the first deposit under modern conditions. To this succeeded the glacial epoch, the formation of moraines, which play a great part in the physical geography, though far less compared with the already-formed mountains and valleys than the interest attaching to their creation would suggest. And at the glacial age we are on the threshold of the history of man.

§ 3. VALLEY-STRUCTURE.

In our district it happens that we have a great variety of valley-formation; from the openest sweep of vineyard-slope to the grandest gorge or merest cranny of a chasm. And not only these, but the great lake-basin of Annecy; and more than one hollow, which in old times no doubt held water, and which though filled up with drift and alluvial soil, still structurally is a basin.

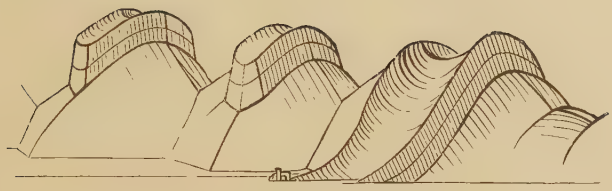
But varied as are all these appearances, three sets of causes will account for each and all; there are really only three distinct kinds of valley structure in Savoy, to which every trough, ravine, or lake-basin can be referred,—with certain exceptions, to be noticed at the end of this chapter; that is to say, either the beds are *bent*, or they are *burst*, or *torn*.

The distinction is a plain one, palpable, and popular; for the country talk habitually distinguishes *Vallons*, *Combes*, and *Cluses*.

A *Vallon* is the rounded shallow vale formed by simple bending of the beds, a synclinal trough.

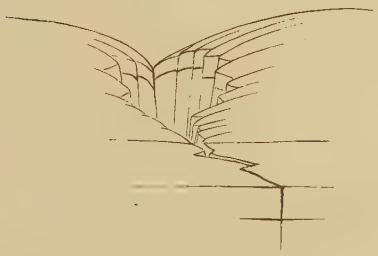
A *Combe* is the deep and often ravine-like dell resulting from a rupture along an anticlinal axis.

A *Cluse* is the gorge, maybe opening out to quite a dale, between "cliffs that have been rent asunder."



1. Vallons and Combes at the head of Annecy lake.

2. Section of Vallons and Combes.



3. A Cluse, or basin and ravine.

XVI. TYPICAL VALLEY-SHAPES.

That is, a vallon is a U-shaped vale, formed of *bent* beds; a combe is a V-shaped dell formed of *burst* beds; and a cluse is an H-shaped gorge left by *torn* beds.

The ground-plan shows that some of our valleys are parallel to the central Alps, lying between long lines of mountain, like wave-crests on a lee shore; these are of the first or second order, the beds being bent or burst, and this in normal alternation. The cross valleys, breaking irregularly through the parallel ridges, and at rough right-angles to the central chain, are of the third,—cluses, and torn.

And it is in these last that the lakes have lain; the valleys of Bonneville and "Cluses," of Annecy and of Chambéry are all of this class.

Typical examples of the first two kinds are seen in profile when you look south from Talloires on the lake of Annecy, sketched in rough abstract in Plate XVI., Fig. 1. Rising from the lake level, the whole land lifts itself gently to the height of some 450 mètres, and then sinks to the valley of the Chéran, away beyond reach of the eye. Stretched across, and over this general ridge, lie long narrow rock-ranges, like the thread of a screw over its core; lifted upon the main wave to 1,200 or 1,300 mètres above the lake, and falling with

the general fall fairly into the level. So you have a row of parallel narrow valleys, walled uniformly throughout their length by these continuous rock-ranges; and in each valley you follow the stream gently upward, till at a height of at least 450 mètres you reach a watershed, beyond which a new stream leads you on, only downward now; both streams, though divergent, being in the same valley.

Now our English dales rest their heads on some high mountain-pillow, and their feet slope far away below. Any lake-basin lies in a hammock, as it were, with both ends raised. But these "vallons" and "combes" lie across their bolsters, with heads and feet unsupported and dangling; the first hint of which is, to a stranger, inexplicably curious and unusual.

These two sorts of valleys usually and naturally lie side by side in alternation: first, a combe, looking as if it had been slit out with two strokes of a chisel; then a vallon, at a higher level than the first, and shaped like a gouge-groove. In reality no scooping nor slitting has taken place; but at the great geological revolution already described immense lateral pressure on the limestone beds has crumpled them into waves, ridge and trough, anticlinal and synclinal, alternately. Then

the tension along the anticlinal ridge has simply burst open the upper beds, leaving the combe pretty much as we see it, and thus doubling the number of valleys. And where this bursting has not been effected, there great vaulted backs, like those of the Reposoir (Mont Vergy) remain in evidence of the undivided wave (Plate XIII.)

And as these hollows have not been chiselled but modelled out of the solid soil, so is there no trace of any recent overlying formation under whose mass the crumpling took place (as crumpling is commonly said to do), and from whose ruin the present shape and fashioning of these mountains gradually emerged by denudation. On the contrary, all later formations are there in place. In the more violent contortions, Gault and Flysch are seen intertwined with Urgonian and Neocomian, proof that they are older than the revolution ; while Molasse appears nowhere (for example) in a higher combe, but only on the flanks of great outstanding buttresses of the great formations, obviously subsequent. So that in these valleys we have mountain architecture almost fresh from the first Great Builder's hand,—structure with which the wear and tear of time has had comparatively little to do since the great revolution in the Flysch-Molasse period. We can study the effects of its power as we study

the plan of some exhumed temple of the East; and find that one agent alone, the earth-throe or thrust variously applied, has sufficed to raise and shape the surface of Savoy into such audacious altitudes as stand unaltered to this day.

These facts are not touched by any doubts as to the circumstances under which this pressure and folding took place. To exactly estimate the elasticity of rock, and how far it would stretch, squash, or smash, is beyond the province of a general sketch of the architecture of these Alps, and calls for the specialties of a skilled experimentalist and profound mathematician. But however this folding and fracture were produced, here they are; and the main shaping of the country can be seen and shown to depend on these, not on mere erosion or subsequent sculpturing.

All attempts to try experiments, or even form conceptions, toward a better understanding of the actual process of mountain building are baulked by several great difficulties, which we may as well face, if we cannot remove them. We can neither completely parallel the facts by our experiments, nor have we data for a full account of the conditions. It must be remembered that what may be rigid in detail to puny or spasmodic pressure may be comparatively pliant in masses league-long and fathom-

deep, under continued constraint of incalculable forces.

As to the consistence of the rock at the time of bending, it is evident that had it been mere putty it would have been squeezed into any sort of shape, and one layer into another, in complete confusion. As the layers are not so confused, we may presume that the material was comparatively hardened: as indeed it must have been, considering how long it was in process of deposition. Then would it not break rather than bend? So it did, to form these combes, like the top layers of a piece of thick cardboard, or thin sandwich, when you try to fold it; and yet bent also where it felt so disposed, where it was softer, where it was more gently pressed. And it has been proved that limestone plates can be bent by using great but slow pressure.

But do we know what degree of solidity had been attained by these limestones, originally sediment in a sea-bottom, and represented in our island by marly clays and sandy soils of anything but adamantine rigour? We have seen that the metamorphic action which altered their colour and varied their crystalline cleavage was, even in this small district, very unequal; and we have reason to believe that it was very gradual in its efforts, and very tardy

in its effects. We have seen that the first work of the revolution was to fold the waves—not to cut chasms or cliffs; and required a softer state of the strata during a protracted period. Then, in a later age, when perhaps the hardening of the rocks had been accomplished by the heat and pressure of the former period, came the wedge-action, tearing chasms and elevating masses whose sides could now stand firm. For all the great precipices, as we now see them, are the chiselled completion, by weathering, of shapes that had been sketched out by folding and cracking in an earlier age, and in softer material; just as a sculptor might work the wet clay with his fingers at first, and, as it dried hard, clear out the detail with an iron tool. A somewhat similar process has formed the cliffs of Norfolk, where sand and clay and chalk, thrown together, have been strangely contorted and upheaved, though without metamorphism or hardening; and then, by weathering and marine erosion, sculptured into precipices several hundred feet, sometimes, in height.

It is well worthy of notice that the bursts are most marked near the point of application of the force which crumpled the whole district; that is, as the pressure undoubtedly originated in the neighbourhood of the Alps, its first onset would

be made on the eastern part of our district. This has been all cracked up into combes. But the pliancy of strata hereabouts would break the violence of pressure before it reached the neighbourhood of the Breson westward; and there a slower thrust would afford a long push and a strong push; acting also upon material which had undergone less violent hardening by the heat of the axial upheaving—exactly the circumstance required for producing those great and generally unbroken folds characterizing the line of the Breson-Veyrier, the sub-Alpine chain, and the Chambotte. A glance at the cross sections will illustrate the gradation in abruptness of form from the Alps to the Jura, for which this conjectural explanation is suggested. It is no conjecture, however, to affirm that these vallons and combes are not due to any of those kinds of erosion to which valley-formation is fashionably referred.

Valleys of the third sort, H-shaped "cluses," are produced by a tearing asunder of the beds. The circumstances of their structure and creation have been already discussed from various points of view. The long ridges from Bonneville to Chambéry, the parallel waves, between which lie the vallons and combes, are not, when seen from the Alps

or the plain, horizontal strata out of which cross valleys are cut, like the chalk cliffs of our Kentish coast. They rise in a succession of gentle arches, one for each mountain block, in this respect anticlinal, but very unexciting anticlinals. (See the sections, Plate IX.) In the case of the mass between Annecy lake and the Chéran valley, we have just seen that the arching rose to some 450 mètres, and owing to this arching the vallons and combes find their watershed, not at either end, but in the middle. We have seen that there are eight of these cross-waves originating in the line of wedges, or secondary upthrust, and divided from one another by valleys of the third order—quiet synclinals, interrupted along the axis by a jagged rent of unknown depth, for the present bottom is generally *débris*. Such a ravine, with its crags and cataracts, the cluse proper, is so striking a feature as to carry both eye and mind away from the less noticeable synclinal, of which the cluse is merely the accentuated axis; and without a model of the district, or such a realization of it as a model gives, this, like many other structural points, cannot be readily grasped. But the longitudinal sections and the analyses of the Breson, Couz, and Parmelan have made their aspect familiar; the great limestone strata gently sloping and

violently broken off at last, showing vertical walls of unknown height, Urgonian, Neocomian, and Jurassic, half filled with foreign soil, or water, whose surface is represented by the cross-bar of the letter H.

As already noticed, the northern side of these valleys usually shows more abrupt cliffs than the southern, that is, beside a dislocation there seems in most cases to be a vertical fault throwing down to the south.

Such being their section, the plan must be discussed; first, as to the relation of their sides. Generally some dislocation along the line of the valley marks how the whole of one side has been pushed laterally out of place, as certainly would have been the effect even of such pressure as formed the mountain-waves, acting upon stuff of unequal strength, and applied with unequal intensity along a not necessarily regular line. Such a dislocation runs along the valley of Annecy, separating the ranges to the north from those to the south, which correspond exactly, but are all more to the east than the Tournette and Veyrier mass. This is partly or principally due to the "wedge," which begins, at the latitude of the Tournette, to develop itself. But a dislocation (and one occurs in most of these transverse valleys) cannot be

produced without disruption of the bed, without the tear which produces a *cluse* or gorge at the bottom of the general and gentle synclinal hollow between the extended domes of the main massifs.

Again, the direction of these valleys of the third order must be noticed. They are jagged, as a piece of bread is when broken; not straight as it is when cut. They show certain traces of an original correspondence of the sides, in spite of wear and weathering, in a more or less disguised parallelism on both sides of the zigzag—a structure which does not at all suggest erosive origin, but rather the cracking or tearing of upper beds; a slight crack at first perhaps, and then enlarged by simple weathering and water power.

A less obvious but noteworthy character of their structure is given in Fig. 3, Plate XVI., which shows in an abstract type how these valleys are wider in the middle and narrower at either end, and deeper in the middle and nearly or quite closed up at each end; forming, in fact, the lake-basins and the only lake-basins of our district in Savoy,—the Lac du Bourget being a Jura lake. The lake of Annecy, for example, lies between two cross-waves, as in this type, in a valley of this order: not simply carved out, for the northern

bank is all too much to the west to fit the southern, while the correspondence of structure is complete, which shows that mere erosion will not account for the facts. The broadest part of the valley and its deepest is between the two summits, from which it gradually closes up at either end; the eastern end being brought to a stop, not with the watershed, which is structurally unimportant, but only after a long zigzag course, with the stop of the formation at the valley of the Isère; and the western narrowing and narrowing till it closes up completely, and is represented (but only fictitiously) by the water-worn gorge through which the Fier runs, and over which an adventurous person might leap, as at the Strid of the Wharfe.

The lake-basin extends from above Faverges to Annecy, a series of four wells, so to speak,—two now filled with alluvion, and two still holding water. These wells are separated by the long lines of Alp-waves, intending at first, it would seem, to be mere walls or dams, creeping down from the bank, across the valley, and up the other side; leaving these four basins as the lowest dip of their longitudinal valleys, like reservoirs in the waterworks, one behind another, one above another. But the continuity of these dams has been frustrated by the wedge-action,

which has pulled them apart along the zigzag axis of depression, lifted all the north-east bank, and pushed it a little to the west, leaving a connected chasm and a clear waterway through the dams. This is seen most strikingly, though in some complication, at Duingt and Talloires, where the double ridge of Entrevernes plunges under the lake,—is broken, pushed west, and lifted to form the Rocher de Cheire. This is again broken, pushed more to westward, and lifted again in the Montagne de Veyrier. No possible erosion could produce this effect, though much erosion has been at work since the first sketch of the valley was struck out.

And if the collected rubbish were swept out of the lake down to the solid strata, we might have a chasm of hundreds or thousands of feet in depth, whose only outlet is its contracted continuation, and even this losing itself at last in the undisturbed plain. In other words, the whole valley is a great tear or rent, widest and deepest in the middle, and disappearing at either end. Thus the lake-basins of Savoy are not excavated, but they are the nearly-choked-up chasms resulting from the dragging apart of the strata by some combination of forces, whose circumstances and causes may be obscure, but their effects are evident.

In each of these transverse valleys we have these phenomena; a narrow and low outlet, and a lofty, deep, and wide basin, which does not always now contain water, but generally shows traces or possibilities of an ancient lake; that is, the shape and semblance of a fissure, crack, or tear. The dislocation which we frequently find present, both lateral and vertical, proves the fact of some tear having taken place. The irregularity of the direction, not to postulate the overwhelming (and now overwhelmed) depth of the chasm at its broadest, shows how improbable if not impossible is its original scooping or carving by water and ice, whatever powers these may use in subsequently undermining its precipices or rounding off its promontories; in fact, in filling up, as we now see it, the abyss created by some earlier and more violent energy.

The subject has been already treated from different points of view in discussing the influence of the various centres of elevation along the wedge, in sketching out the "cross-waves" or east-and-west mountain-ranges (Chapter 2, § 2); and again in showing the distinction of successive thrusts or throes, which followed the first upheaval of the central Alps themselves, and then completed the corrugation and cross-cutting of the secondaries on their flanks (Chapter 4, § 2). A mere lateral

thrust was not all that occurred, nor indeed was a mere lateral thrust all that must have happened during the long age of revolution in its successive and varying phases.

To get these cluses no erosion will suffice, for they are *broken*. No lateral pressure will suffice, for they are *torn*. The only force that will adequately explain them is vertical upthrust. And this vertical upthrust we have traced in its possibilities, as a result of the general causes of Alpine upheaval; and in its existence, in the wedge, where along a line, but discontinuously, a distinct upthrust has taken place, for which we cannot account merely by considering it as a case of crumpling under lateral pressure.

And with these facts in view, it will not be difficult to grant that in this second stage of upheaval, the process which drove home the wedge supplied the elevatory power which vertically lifted each of the mountain massifs into a gentle dome, and dragged apart the strata, as we see them torn, into transverse valleys or cluses. Where the dome was lifted highest, the strain being greatest would drag the beds furthest out of their old position. Between two such points the disruptions would be widest, and the chasm deepest: which is exactly what we see in the result. Subsequent weathering

would broaden the broadest parts, but deepen nothing; and *débris* brought in by water and glaciers would go to fill these gaping abysses, still leaving depth enough to hold water as at Annecy, or failing that, a flat floor as at Chambéry or Cluses.

There remains one set of little valleys to explain, the exceptions alluded to in the beginning of this chapter. They are the little dells running into the cluses just behind the great Breson-Veyrier fold in Urgonian; fully shown and discussed in the analyses of the Breson, Couz, and Parmelan. They are the result of erosion following upon, and rendered possible by, the breaking of upper layers in the act of folding over. And any other such little steep dells running down into the great cross-valleys are the effect of the wearing away of soft substrata, and collapse of the superincumbent Urgonian. But all such are very small in nature, and unimportant in the general structure of the country.

These remarks must be taken as applicable only to the district in question. With the formation of lake-basins in general they do not deal. But as far as Savoy extends, it seems impossible that any subsequent agent, such as ice or water, could have cut the valleys deeper than they were left

at their very creation. Vallons, combes, and cluses, great or small, have all been bent, burst, or torn by those earth-throes which undoubtedly raised the mountains, and all that has happened since has tended only to their obliteration.

CHAPTER V.

THEORIES OF VALLEY ORIGIN.

§ 1. SUBSIDENCE.

SO far we have been content to note the aspects of our own little alp-land, suggesting only so much of its history as might explain each feature that offered itself to our view. But the general question of the shaping of mountain-land is still one of the disputed things in physical geology; and has given rise to many speculative theories, which can be received under three heads, as they attribute valleys, and especially lake-basins, to subsidences, to erosion by water, and by ice.

Of physical theories the cheapest to produce are always the most expensive to apply. The smaller the outlay of observation and thought, the greater is the demand for original causal and creative power; so that vulgar philosophy postulates for every trifling effect a separate cause which alone could move or make a world. The old phrase which used to be thought to explain any-

thing was "a grand convulsion"—something, no doubt, in the style of a picture by John Martin; thunderstorms, volcanoes, earthquakes, the Noachic deluge, and a general collapse of the firmament.

But theatrical cosmogony of this kind is not only distressing to contemplate, but unphilosophic to advocate; since all natural analogy teaches and preaches the economy of means to ends. Consequently, people have thought it wise to judge of hypotheses as of tenders for contract,—by the offers they make: giving preference to that which postulates least and promises most; to that which pretends to deduce a whole universe of events from the merest chance of a cause to start with, and the strictest mechanical automatism to follow.

And yet this very habit of *à priori* assessment of any prospectus of creation resembles the cheap theories it professes to destroy, in that it predisposes the public to grasp at any epigrammatic principle, without thoroughly enquiring whether it is sufficient; thus an indiscriminate uniformitarianism may be as fallacious as the vulgarest speculative naïveté. What we need is, not to fancy, but to find; not to argue, but to observe; and it is more satisfactory, both to common sense and to science, to give an exhaustive, if empirical, explanation of proxi-

mate causes, than to attempt a hasty generalization to ultimate *origines*.

With such principles in view, let us criticize the three groups of theories of valley-formation; and see if these ideas, even where most fashionable and fortified by high modern authority, are really in accordance with the facts.

First, as to Subsidences. These may and do result, especially in a limestone country, from the gradual undermining of limited districts by subterranean streams, holding in solution enough carbonic acid to eat away the crack, through which they filter, into great tunnels whose arches finally become too extended to bear up the surface. Here and there on the mountains' flanks you may see a swallow-hole in the soil (*Katabothron*, it would be called in Greece), down which a stream disappears, romantically reappearing under some great crag, a fountain of limpid water welling out over the meadows. Clear though it looks, the amount of limestone carried away by such a stream is surprising; and we cannot but believe that its excavations are considerable, and that the subsidences into these are extensive. With all circumstances favourable, and unlimited time allowed, very large valleys might be thus formed, and in other districts no doubt *are* thus formed. But

we have seen, as a matter of fact, that all our Savoy valleys have been otherwise formed, as can be shown from the structure of their beds. Moreover, when one considers the almost organic regularity of the structure of these valleys, the conclusion forces itself upon the mind that they are a co-ordinated whole, created by one set of interconnected causes, not by various independent accidents.

Still less likely is it that great quasi-volcanic subsidences have here been at work ; that is, the sinking of limited areas, as opposed to the troughing of the whole district in such a way as we have described. The two causes are totally distinct, and the resulting appearances would be quite different ; the sweep of a vallon, the cleft of a combe, the chasm of a cluse, are quite unlike the pit of a subsidence, which would be a sunken space outlined by faults ; a structure which, if it exists at all, does not characterize any of the greater Savoy valleys.

Nor, again, are our valleys gaping, vertical faults, if such are possible. There are faults enough in these mountains ; but in the valleys one traces the beds, interrupted but not displaced, from one bank to the other. And yet we have seen that the cluses are lateral dislocations ; the whole bank on one side has been pushed more up or down

the stream, without necessary alteration in its level.

In short, no local, independent, unsystematic, physical causes need be called in to account for our valleys ; nor, indeed, would such be of any use, if they were to be invoked or invented. Nor in attributing the modelling of these mountains to such earth-throes as have been described, do we suggest the occurrence of any cataclysmic convulsions ; for it has been shown that the Revolution period was a long geological age lasting through the formation of the three separate series which make up the whole tertiary epoch. And for the creation of such loops as that of the Breson, sudden and violent force would certainly be useless ; only a long pull and a strong pull can bend without breaking the mighty strata of limestone.

Even the burst and torn valleys require no explosion to account for them ; a little rise in the soil,—a crack, wider to-morrow, spreading next day, and continuing for only a little season of the great Tertiary age, would soon produce the combe of St. Ruph, or the cluse of Thônes.

§ 2. FLUVIAL EROSION.

Another set of theories seeks to explain valley-formation by Erosion. Let us review first the

various operations of erosion by water, to which not only gorges but valleys, especially in limestone countries, are commonly attributed.

Joints and faults in the strata afford starting-points for the infiltration of water, which enlarges them,—both by chemical means, already described in the preceding page, and by mechanical means of two kinds, to which popular belief adds a third of less certain proof. First, the percolating drops in winter time freeze, expand, and quarry the rocks like a blast of gunpowder; and this is the most important of the processes known as weathering. By this, a valley once formed is continually widened, as no doubt are our limestone vallons, combes, and cluses; and this widening formerly went on at a much greater rate, when the walls were steeper, and their equilibrium less stable. But weathering postulates some starting-point; and it is the secret of this starting-point which is the secret of valley-origin.

Secondly, any loose pinnacles or boulders are carried away by the floods or spates of the stream; so that unhardened, uncemented, sandy and gravelly soils are liable to be cut into by the rivers which drain them. At the same time, many such soils were more or less made by those very rivers, whose function really is, not to be always cutting holes

but to be always filling up holes; and their block-carrying power exerts itself rather in steep rock-ravines, to keep them from being choked up, than in creating new hollows in comparatively level ground.

So that we have, in combining chemical and mechanical means, a possibility of valley-formation by water-power. Tunnels eaten out by acidulated water percolating through cracks; falling in; blocks carried away down hill; frost continually quarrying down the walls, would make a narrow steep valley, widen it and deepen it by retrogression from foot to head. But which sort of Savoy valley would that represent? Not a vallon, for there the beds are not broken or cut through, but bent. Not a combe, for that goes up-hill and down the other side, as a valley of fluvial erosion could not possibly do;—except on the extraordinary chance of the creation of two similar valleys in one straight line starting down hill in different directions from the same point; which, even if it happened once, would not happen over and over again, as in Savoy. Nor could a cluse be so formed; for a cluse is generally a basin, and a valley of fluvial erosion could not be a basin; for that would imply that its stream should flow down and up again. Something like a basin by chemical erosion might

indeed be possible, but that would be what is known as a subsidence, already discussed. And just as subsidences can only be asked to account for the most trifling holes and hollows in Savoy, so fluvial action is answerable for only the least important of the tiny dells and dingles that seam the mountain sides, as in the Breson and Parmelan; and for mere river-gorges, as of the Fier;—not for any of the important valleys, whose "organic" interconnection (to make bold with an apt analogy) and actual individual conformation show how little they can have been created by such causes.

There is one other power attributed to streams, the "continual dropping that weareth away stone;" filing by the friction of blocks and sand carried over the rocks of its bed. In some torrents we see round basins scooped, and great slabs scraped down; and the mere rounding of pebbles in any swift stream shows possibilities of cutting a trough in the rock, in the course of some millions of years. But besides that, this mode of valley formation is quite hypothetical; for it is one thing to round a rolling stone, and another to carve a fixed rock; and one thing to scour a basin like a pint pot,—and that in the most furious rapid of mountain torrents,—and quite another to saw out a ravine from an unflawed dam, over which the water might

have as well risen and leapt. Beside all this, the objections, already drawn from the structure of these valleys of Savoy, apply here with no less pertinacity. Water-action, whatever it could and did effect in other lands, could not have originated, however it may have finished, the work of valley formation in these Alps.

§ 3. GLACIAL EROSION.

Failing all these explanations, it has been supposed that the valleys have been wholly or partially excavated from shapeless Kraken-mounds of rock by glaciers, which, as we know, at a certain period had a much greater extension than at present. As the Secondary period was the age of tropical ocean; the Eocene, that of upheaval; so the Pleistocene was the epoch of Glaciers.

The proofs of this extension in our neighbourhood, and the causes of it, are not worth our while to dwell upon; the former, because they are so numerous and plain; the latter, because they are so numerous and visionary. Every valley in the Alps was once the bed of a glacier; every mountain side, if cleared of its soil, would show the scars of a glacier; every heap of stones in the fields, every bank of pebbles in the streams, was

brought there by a glacier. Castles are built on glacial mounds; houses are built of glacial blocks, and on glacial blocks, cemented with lime burned from glacial erratics; roads are paved with glacial *débris;* gardens and vineyards owe their soil to glacial drift. And these ancient glaciers reached the high mountain tops,—the Breson and the Salève; though a few, like the Voirons, probably emerged.

This being the fact, we shall not delay to ask here whether it was caused by a change in climate of many dozens of degrees, or only 4° or 5° Centigrade, as M. Ch. Martins holds: a change in the earth's axis, or orbit: in this globe's heat, or the sun's heat: rearrangements of the continents or the Gulf Stream: any elevation of the Alps, up to 20,000 feet, or any depression to match: escapes of steam from interior cavities of the earth, or enormous evaporation from an ocean not yet cooled down, not yet grown salt, not yet confined to present limits,—and immense snowfall in consequence of all this moisture: or again, immersion of Sahara, and consequent absence of warm south winds:—the mere naming of these surprising speculations is growing tedious. But the conditions required, and which they severally seek to satisfy, are,—more cold; more wet; or both. More cold, to keep the tops of the hills just below

freezing point; and more wet, to keep them better supplied with snow.

Somehow more cold, more wet, or both, did actually occur, and create the glacial epochs,—one, two, or three of them; which undoubtedly filled all Northern Europe and all the Alpine district with glaciers; which (they say) creeping slowly over the solid strata, ground and gouged and gnawed out the valleys, and not only the valleys but the lake basins. Without disputing whether this *could be* the case from the point of view of the ice, let us see whether it *was* the case from the point of view of the rock,—in our district at least. Immense ingenuity has been spent on the mechanics of ice. But I do not know that a strongly-glaciated country has yet been studied, and its structure understood, in such a way as to put the question of its shaping beyond the region of mere conjecture.*

Grant for the sake of argument that a glacier, or rather the stones and sand embedded in it, can erode its bed into a basin; would that produce the sort of valley which we see in Savoy?

* While this book was in preparation, there appeared the "Quarterly Journal of the Geological Society" for February 1883, containing the Rev. A. Irving's paper on the "Origin of Valley-Lakes," which criticizes the glacial theory from much the same standpoint as the one here taken; and promises a new departure in this study, with hopes for great results.

To take our already made division,—a vallon would certainly not be the result of glacier action, resulting as it does from a simple bending of the beds. A combe is in some respects the sort of valley which might be supposed to be produced by glacial cutting; being straight, and showing simply a gap whence a portion of the otherwise undisturbed strata may be supposed to have been chiselled out or eaten away; in the manner in which ice-erosion might conceivably act. But a combe is always the lengthwise slit of the cylindrical anticlinal ridge; as if—permit me to repeat the childish simile—instead of cutting your roly-poly pudding across, you cut it from end to end, taking out slices such as you take out of a turkey's breast in carving at dinner. Now, how could a glacier, with any amount of erosive power freely granted it, sit on the top of a ridge, crawl along the top of the ridge, eat out a gutter along the top of the ridge, leaving a double ridge now on either side?—never going straight down into the vallon which opened out on either side,—which was formed in the preceding geological age, and which would be its natural and necessary bed. Again, to form a glacier you must have a *névé*-reservoir; and what such accumulation of snow is possible, for example, in the anticlinal ridge between the Entrevernes and Trelod vallons, if

a ridge (like Mt. Chambotte) ever existed there? But if it be thought that these combe-glaciers were offshoots from the great main valleys, it must be explained how they could work steeply up hill —as the combes do—from either end, meeting at a height several hundred yards in the middle, like the engineers who made the Mont Cenis tunnel.

It is impossible that any of the long valleys parallel to the central Alp-chain were made, or even enlarged, by glaciers. Then as to the cross valleys the lake-basins, the cluses; to explain which Sir Andrew Ramsay proposed the theory of glacier scooping, which can be shortly stated thus:—Ice, he thought, creeping down a slope, steeply and swiftly, exerts little pressure; but as the inclination and speed decreases, the pressure increases; friction is energetic, and the rock-bed chiselled away. Further down the glacier, towards the valley-foot, the ice gradually melts away, gradually relieving the ground of its pressure and of its friction. So it scoops deepest where it presses most; making a basin there, and leaving a dam at its foot. This is, in short, the glacial theory of the formation of lake basins.

Without entering into general criticisms, let us examine the cluses or cross valleys of our district. Their structure has been already detailed, but must

now be reconsidered with special reference to the possibility of their glacial origin.

Beginning from the south,—passing over Chambéry as not having sufficiently examined both banks (though we shall have something to say about it further on),—the Chéran runs through the first great cluse. Suppose this had been cut by a glacier, what manner of glacier was it? where was the snow-fountain or Alp-cradle? It could not have been a limb of the Isère glacier; for a great mountain wall shuts off the head of this valley, a *cul-de-sac*, from the Isère. It must have been, in its first condition,—before the cluse which it had to make was cut,—a series of disconnected snow-masses, lying in the wave-troughs, whose motion would be *across* the line in which they are required to flow. Even supposing the cluse to be already stretched out, the glacier of the Chéran must have been fed from small combes where the névé lodged in nooks and niches; not a very great fountain-head for the glacier which is to cut a valley twelve miles long, between one and two thousand mètres deep, and descending only three hundred mètres in its whole length. It might be supposed to have increased as it went, from tributary glacier-streams; but the outlet to this valley, as usual with a cluse, is its narrowest

part: and we cannot suppose the glacier to have melted away just before this outlet, for the descent is not sufficient to reach a much warmer climate; indeed, the lowest point in the cluse of the Chéran is higher than the highest in the valley of the Isère (except at its extreme head), in which there certainly was a great glacier. Here is a nearly level, very deep crack across the ridges of a strongly corrugated country, connected with no great glacier, and ending in a ravine; such a trench as a glacier would be most unwilling, if able, to dig. But there is more in this valley than that. It is a great lateral dislocation. All the southern bank has been pushed eastward some two or three miles: as we have seen in Chap. II., § 1. The glacier could not have done that; and that could not have been done without producing a crack, a chasm, a cluse; which subsequent weathering widened, and subsequent ice-action polished, but which no erosion created.

The next valley is that of Annecy; not straight as the Chéran, but very crooked; but in other respects like the former. Although its river rises in the Mt. Belle Etoile, the ground is low between Faverges and Ugine; Faverges being 50 mètres above Ugine, and 140 above Annecy lake-level. So that the whole zigzag ought to be considered

as one valley—though with a watershed across it, not a mere moraine-mound, but the meeting of the Tournette and Sambuy; and yet with a basin between this watershed and its lowest foot. The highest part of the valley, the watershed, is between the lowest mountains; the deepest part of the basin is between the highest mountains; and the foot of the valley continues indefinitely to the westward under the Molasse, and through the sub-Alpine and outlying Jurassic chains. From the sections it can be gathered that all the chains on the south side run down into the valley, terminating beneath the surface of lake or soil; while the chains on the north-west start at a high level. That is, the northern bank is physically formed by a sudden elevation of the strata; the southern, by a strong depression. Once more, the lateral dislocation which characterized the valley of the Chéran marks this still more strongly.

Now, with these physical features, which a glacier cannot pretend to produce; and with the watershed barrier between Annecy lake and the inflow from the Isère, what ground is there for attributing to the sea of ice, which once filled all this country, any special cutting out of this valley? The fact of the watershed of Faverges shows the contrary. For the glacier of the Belle Etoile would be but

small, while the glacier from the central Alps would have cut this bar away as a preliminary step. And then, the deepest part of the valley is not its steepest, for the incline is gentle throughout,—steepest, if anywhere, nearer the head ; while the lake lies at its foot, in hollows formed as described in Chap. IV., § 3, page 139. It is a mere matter of fact that the valley of Annecy is not a glacial excavation.

Take next the valley of Thônes. From the analysis of the Parmelan and Veyrier, it has been seen how this is a synclinal trough, narrowest and shallowest at its mouth, and that is between the lowest hills ; where the hills are higher the valley is broader, and, to judge from its level surface and modern soil, has been deeper ; a real basin, indeed. The vertical crags on both hands have receded irregularly by weathering and éboulements ; but the zigzag plan of this wall precludes all idea of its having been chiselled by ice ; which, if it cut, and cut in homogeneous rock, as this certainly is, would cut straight, not vandyking hither and thither, like forked lightning, however it might meander like a stream. The valley of Thônes is a case of the general physical structure of the country ; the necessary consequence of the formation of all its other features, and ice has nothing whatever to do with it.

The little dale of la Verrerie is a mere rift, not running through more than one or two longitudinal mountain waves; though continued in a rudimentary way in the dip between Achenaz and Glaire, and (to judge from the map) something of a break in the ranges of the Balme and Traversière; which can be easily understood, if the valley is seen to be a tear; but unexplained by any glacial origin. So, too, is the gorge of the Usses at the Pont de la Caille understood, if referred to this cluse; of which it is probably a prolongation, concealed under the molasse, but cleaving the Salève range.

The valley of the Bornands is likewise only understood as a crack across country. From Flumet you rise six or seven hundred mètres to the Col Aravis; down to the Nom, up to St. Jean de Sixt, down between Domigny and Traversière, past Petit Bornand to the Gorge des Evaux;—the whole, one obvious break in the limestone, dividing the whole massif of the Dorans and Mt. Vergy from that of the Charvin and Traversière. The gorge at the end, as already suggested (p. 51), may be the same with that crack at Monetier which divides the Petit and Grand Salève, and whose presence is so difficult to explain except as an actual crack.

But, undoubted as the continuity of this valley

is, it is interrupted by no less than two watersheds or bars across its course,—things which do not make matters easy for a glacier. For, take the Col d'Aravis; either the glacier must have climbed up and crawled over, or else have sat on the top and worked down on either side; and both these operations are contrary to the nature of glaciers. A hypsometrical map, or model, makes the difficulty plain at once. The Bornand valley is not one which could be taken as a type of the result of glacial erosion.

Then comes the great valley of Bonneville-Cluses-Sallenches. This is like that of Annecy in most respects. Though now filled up with alluvion, it has once contained two basins—one above Bonneville, and one at Sallenches, just as the cluse of Annecy was seen to be the combination of several basins, by the bursting of their dams. From Bonneville to Cluses the southern bank is formed by the strata dipping down, indefinitely, beneath the soil; the northern bank, exactly as at Annecy, by a sudden upthrust (shown in the longitudinal sections, Plate IX.) This is not an affair of ice, but of physical action. The valley from Cluses to Sallenches is quite different; here there is no fault. At Cluses you see the arched strata, continued from the Reposoir, match on either hand; while the

twist of the Nant d'Arpenaz can be traced across the valley, under the Dorans, which are of the same chain with the Aiguille Varens, Rochers des Fiz, and Dent du Midi, thrust out of the straight line by the Chablais wedge. So that we have here every condition of a torn "cluse," through which the great glacier of the Arve has run; but not depending for its direction, extent, shaping, on the glacier, for it must have existed long before the glacial period, being a necessary outcome of the general formation of the Chablais. All the Varens mass is pushed south; has carried the Reposoir-Dorans with it; as you see from the way they curve round as if to catch up their lost companions, who, driven too hard, have broken away from them:

> "But neither heat, nor frost, nor thunder,
> Shall wholly do away, I ween,
> The marks which once of love have been."

The consideration of the valley of Chambéry has been deferred until the others have been described, because its southern bank does not appear in the sketch map, and can be more readily understood on the analogy of the great cross-valleys of Annecy and Bonneville. It is really, at Chambéry, the union of three distinct valleys. To the east there is a depression, a synclinal

trough between the Chambotte range and that of the Mont du Chat, in which lies the Lac du Bourget. To the west, a similar depression (in which lies Aix-les-Bains) separates the Chambotte from the sub-Alpine range ending in the Dent de Nivolet. Breaking across into these obliquely is the broad, ragged valley from Montmeillan to Chambéry, whose narrow lower end is a synclinal trough made by the Neocomian and Jurassic beds of the Nivolet dipping under the town of Chambéry and rising to Mont Joigny and the mountains of the Grande Chartreuse. The middle part of this valley appears to be a broad basin filled up with modern alluvia and glacial drift of the Pleistocene epoch, through which rise islands of the lower strata, both Neocomian and Jurassic. Toward Montmeillan is a low watershed, the surface of which is formed by glacial deposit—the moraine of the ancient glacier of the Isère. It is only this short and shallow space which is not distinctly the result of the crumpling of beds; and here we have the characteristics of a cluse. The mouth of it is narrow, showing plainly a continuity of the synclinal beds, as at the Gorge of Dingy, the foot of the valley of Thônes. The basin is between the higher hills; here not reaching down to join hands, as at the mouth, but standing back and

apart, exactly as in the diagram of the cluse (fig. 3, Plate XVI.) And though the communication with the valley, and in old times with the glacier of the Isère, is open, the islands of rock show that if all surface deposits were cleared away there would still be serious heights between the Isère glacier and the Lac du Bourget. No doubt this may well have been no obstacle to the general filling of the whole district with ice; but if the Chambéry-Bourget valley was the result of erosion by a tributary of the Isère glacier, why was this erosion not regularly downhill, but first up and then down? It cannot be said that, after the Chambéry valley had been formed, the Isère glacier left it and went on digging its main bed deeper; for the watershed is quite away from the main line of this latter. It is not where it should be if a glacier scooped the valley; but it is where it should be if the valley was started by tearing apart the sinking beds between the mass of mountain to the north and that to the south. Each longitudinal ridge and valley keeps its relation right through, as shown by these islands, though sinking and irregularly rent; the cross-valley is not a gouged or chiselled gutter driven across country, as it would be if created by erosion.

Though only an elaborate relief-model would show the fact palpably, enough has been said to

describe the structure of all these transverse valleys of Savoy. They are all owing to two conditions, a general synclinal dip, and a tear or fissure along the axis; and this tear is always narrowest at the mouth, where the synclinal is most marked, and widest and deepest in the body of the trough. All these "cluses" are of the type shown in Plate XVI.; none of them such as glacial erosion could or would have caused.

In fact, there is no valley in Savoy whose existence can be accounted for on the glacial theory; and the general structure of this country, undoubtedly glaciated, and very strongly glaciated, points to the general conclusion that in one large district of the Alps, at any rate, glaciers did not excavate valleys. How far this can be shown in other districts must be the enquiry of separate works based on a more careful study of the structure of mountains than is generally attempted.

CHAPTER VI.

FACTS ABOUT ICE.

§ 1. THE GLACIER BED.

THERE are always those who flatter themselves that, when much is to be said on both sides of the question, a judicious eclecticism cannot fail to hit the truth. Some such hope as this must have influenced M. Gabriel de Mortillet, one of the chief authorities on the geology and mineralogy of Savoy, to whose works this book is greatly indebted. M. de Mortillet considers that though the glaciers did not cut lake-basins and valleys, yet they formed them finally by sweeping away the ruins of an earlier world with which they were encumbered. He does not ask us to believe that any but the smallest mountain tarns were scooped by ice; yet molasse and drift being soft and unresisting were ploughed and swept away, as by a great broom.

He remarks, and rightly, that molasse and the nummulite formation seem mutually to exclude one another. And we have seen that the molasse is

really the continuation of that sort of deposit which in the early stages of the Revolutionary epoch was Flysch; in the later, laid down only at the foot of already formed mountains. The belief accepted about our English hills, that they were once overwhelmed under miles of now removed formation, is hardly tenable in Savoy. If they were, what was the formation?—what traces are there of it? The early Tertiaries are in some places pretty deep, but their usual thickness appears where they are folded with the secondaries. The later Tertiaries filled the undulations of the lowland district, but do not exist in the upland. If they were cleared by glaciers from every upland valley, why not the equally friable earlier soils?

And yet there was in every large valley, especially in the cross cluses, an enormous amount of denudation. This is always greatest where the disruption has been greatest. In some vallons it would seem that hardly a bank has been stirred since the beds were folded into waves. But in the cross-valleys the loss of substance has been immense;—not because there has been more ice there (for in the glacial period all these valleys were glacier-beds); but because the "wedge"-forces treated their banks rudely to begin with, and left them peculiarly exposed to weathering. But all

this denudation is of the solid Urgonian and Neocomian; not merely of loose *débris* or drift.

And now the question proposes itself—what is the behaviour of a glacier with respect to a soft and friable subsoil? Does it plough it up?—and if so, when? Suppose a glacier were to enter a valley filled with loose soil or gravel, what would happen?—or rather what *does* happen, what *did* happen? And generally, what is the part that glaciers play in the shaping of the earth?

"In 1818," says de Charpentier, "the glacier de la Tour, in the valley of Chamonix, advanced, without ploughing up the ground, about eighty feet over a gravelly bed, not covered with earth; but at the end of that space, it met with certain meadows whose soil, being rather *marshy* ground, was entirely upraised and overturned."

In the same year the Bossons glacier advanced so that it was feared the road would be swept away, instead of which it produced no disturbance in the soil, which is there quite soft, arable ground.

And now the glacier of the Bossons having retreated immensely, what sort of a bed has it left? Bare ploughed rock? a scooped hollow? a carved ravine? Not at all; but a causeway of the loosest stones—an embankment which a railway

would despise as far too loose to lay sleepers on. And this just where its slope and speed decreased; —where the friction, according to the glacial theory, should have increased. As a matter of fact, whatever the glacier was expected to do, it has flowed over all the loosest soils—except downright mud, and except where, as at the Görner glacier some thirty years ago, a soft bank stood right up in its way, and was simply crushed, but not eroded.

In 1853, during a temporary extension of the Glacier des Bossons, it was stopped by a large rock in the way. The ice accumulated behind it, until it acquired sufficient weight to carry it away.*

Ice, then, sometimes overrides incoherent deposits of sand, sometimes breaks down opposing rock-walls; and that on a large scale in ancient times, as can be shown from examples quoted by Professor J. Geikie in his interesting and popular works, "Prehistoric Europe" and "The Great Ice Age."

At Elbing and Frisches Haff in Prussia the lower boulder-clay—that is, the bottom-moraine of the ancient glaciers in their earliest epoch—has been underlaid by a bed of nearly two hundred

* Venance Payot: "Oscillations des Glaciers dans la Vallée de Chamonix."

feet of fine stoneless clay, in which all the shells, except the very thick *Yoldia*, have been crushed; and the whole bed so compressed that it has to be blasted out with powder. Here was a great field of the softest clay, over which the glacier passed; not ploughing it away (still less eroding the rock beneath), but rolling it like dough under a rolling-pin.

On the other hand, when a rock-wall stands against it, the glacier simply breaks it away. For example, Professor Geikie relates how at Möens Klint, in Denmark, the second glacial stream was opposed by chalk walls left bare by interglacial erosion; against which "it pressed with enormous force, rupturing and smashing the rock, dragging huge masses of it out of place, squeezing tongues of boulder clay into the fissures; and in short producing all the wild confusion and disturbance which is now so conspicuous a feature at Möens Klint." Again like a roller, not like a plough.

"At the first blush it may appear hard to believe" (says Professor Geikie) "that a great mass of solid ice could ever pass over the surface of incoherent deposits of clay and sand. But the appearances presented by these deposits tell their own tale, and teach us, as we have been taught before, that our preconceived notions of what Nature's forces

can and cannot do are often wide enough of the mark. It is needless to refer one to the petty glaciers of the Alps and Norway to prove that glacier-ice cannot both erode its bed and accumulate *débris* upon that bed at one and the same time." [Professor Geikie accepts the popular theory that the glaciers of the Alps *do* erode their beds, and consequently cannot form bottom moraines; which everyone is not prepared to admit.] "A mountain-valley glacier is one thing—a glacier extending far into the low ground beyond the mountains, and, it may be, coalescing with similar extensive ice-flows, is another and very different thing" [but only in degree]. "No considerable deposit could possibly gather below Alpine glaciers like those of Switzerland and Norway" [no *considerable* deposit perhaps, though *moraine profonde* exists in an Alpine glacier-bed]; "but underneath glaciers of the kind that invaded the low grounds of Piedmont and Lombardy, we know that thick deposits of tough boulder-clay crammed with scratched stones did accumulate; and not only so, but that *these glaciers flowed over incoherent deposits of sand and clay containing marine shells of late Tertiary age, without entirely obliterating them*" [the italics of this important sentence are Professor Geikie's] . . . "It is enough for the geologist to show how the re-

markable distribution of the interglacial beds, and the various phenomena presented by these deposits, indicate that ice *has* overflowed them. It is needless, therefore, to tell him that the thing is impossible." *

In our district, quite independently of anything that has been written on the subject, the fact cannot fail to strike a thoughtful observer, that even Alpine glaciers during their greatest extension overflowed,—without ploughing away, as M. de Mortillet thought,—the most friable Tertiary beds; as well as their own *moraine profonde*. And even in modern small and steep Alpine glaciers, to which Professor Geikie allows and attributes erosive power, what, as a matter of fact, do we find underneath them? Where they have recently receded, is it bare, scraped rock? Not at all; but a heaped-up causeway of dirt and stones. A visit to the Glacier des Bossons, or that of the Bois, will show this.

And all that is known of the actual condition of the under surface of glaciers was known to Agassiz,—of whom it may well be said, in the words of Alphonse Favre, "Les théories passent, les observations restent." Agassiz describes in his "Etudes sur les Glaciers" (Chapter XIII.), the bottom of those vaults which undermine glaciers,

* "Prehistoric Europe," pp. 294-5.

and through which unfortunate or adventurous climbers have occasionally penetrated mazes such as those

> "Where Alph the sacred river ran,
> Through caverns measureless to man,
> Down to a sunless sea."

These caverns are not floored with bare rock, but with mud, gravel and stones of different sizes up to a foot in diameter, dropped through crevasses from the top. And whenever a glacier retreats, says Agassiz, it leaves not bare rock, but mud. This is the *moraine profonde*, over which the glacier creeps: not as a glazier's tool, with embedded cutting diamond, runs over the glass; but as a cook's rolling-pin rolls the dry flour over the soft paste, and that over the board.

We have, in section—

Ice.
Moraine Profonde.
Tertiary Soils.
Secondary or Primary Rock.

And this, as far as we have means of knowing the actual state of the glacier-bed, apart from guess-work, is really the case. Of course, in the massif of Mont Blanc and such high Alps we see no such late Tertiary beds, where none were laid down; during the earlier period the Alps were rising, and

their *débris* formed this soil in the lower lands, and during the later period the Alps were all under ice, and have been more or less so ever since.

Continually in Savoy you find soft molasse and other Tertiaries on the spot where the glaciers have been ; and which glaciers, if they plough and scoop, should have cleared away. After the Miocene sea retreated from its beach on the Breson and the Semenoz, leaving the later, marine, molasse ; after the last throe of the revolution had passed away, a comparatively warm climate prevailed, though not nearly tropical ; for the box-tree grew at Chambéry, and the elephant and rhinoceros fed near Geneva and Albertville. During this age, the beginning of the Pleistocene epoch, *débris* of the various kinds of Alpine rock were laid down with neatness proportioned to the fineness of the material, and here and there shells and insects, such as are found at Chambéry.

Then came the Great Ice Age, recurring once,—some think, many times ; and the glaciers passed over all these beds, which unlike earlier strata had not been hardened by any metamorphic action, nor cemented by any calcareous mortar. Over these rubbish-heaps rolled the glacier like a great steam-roller ; not ploughing them apart, still less clearing them away. Instances are given of

sections in which (*e.g.*, Professor Geikie's "Hailes Quarry" section) a trough appears cut in beds of this sort, and filled up by bottom moraine of the glacier, from which it has been concluded that the glacier ploughed this trough. But if the glacier ploughed this, why so trifling a groove? Why not clear it clean away? For the trough is just what a preglacial or interglacial river would and could cut; and just what a glacier flowing down the river track would make no account of, but simply swamp under its bottom moraine. Indeed in Mr. Geikie's sections, pp. 154, 161, it is as common for the interglacial deposits to displace, that is, fill up holes in, boulder clay, as for the boulder clay to take the place of firmer soils.

How was it then that the lake-basins were preserved?

The creation of them, as cluses, pre-supposes a great depth of chasm; which swallowed up its share of tertiary *débris* and drift without in every case being quite filled; though in most cases the basin has disappeared.

Then came the Interglacial period or periods; fresh deposits over the former, not more indurated than before. Then, more glaciers, no further ploughing the still softer soils. Even in these higher Alpine valleys it is probable that

the enormous, mile-deep mers-de-glace have rolled over bed upon bed of alternate clay, soil, sand, stones, pebbles, gravel, without displacing or disturbing them. The only result has been that pebbles thrown down at random have been pressed so as to lie in the flattest way, with their long axes horizontal; the soil shows signs of considerable pressure, but of no such compression as that experienced by some conglomerates, where the pebbles have been broken and crushed.

To carry such ponderous cargoes as these glaciers and all their boulders over such unresisting roads, think what waggon-wheels must have been needed, when the softest indiarubber tire and smoothest-oiled axle leave their rut on the turnpike highway. There is a fact of which the evidence is simple and the idea clear to grasp—that the advancing motion of the ice could, at the same time, carry on its top an incalculable weight of cargo in the way of boulders, and yet press under itself and them a pathway of loose stones and sand without disturbance, or riving, or rugging, or rending, or tearing, or ploughing, or cutting, or any such power usually attributed to glacial action.

Professor Geikie tries to explain this in showing that among the hills ice went fast, and left roches moutonnées and no boulder clay; on the plains,

slowly, leaving boulder clay and no roches moutonnées; the farther from the centre of glaciation, the weaker the force: where the ice moves faster, it erodes; where slower, it accumulates.

This is exactly the opposite of what the other advocates of glacial erosion maintain; their principle being that where ice moves fast it does not erode; where slowly, it does. And it does not account for the facts in Savoy—which are that where ice moves fast it does accumulate bottom moraine; and even in high Alpine valleys it does not scoop; as in the lowland valleys in does not scoop either. So that M. de Mortillet's theory is hardly tenable; nor is the ordinary conception of the action and motion of a glacier. Truly "our preconceived notions of what Nature's forces can and cannot do are often wide enough of the mark."

2. THE MOTION OF GLACIERS.

We have just seen how the glacier's motion is not, in its results, like that of a plough, but like that of a roller; it presses, but does not remove any dry subsoil, however loose and friable; only displacing it when marshy, as a wheel squeezes along a puddle of mud; and it is only when the ice-flow encounters the obstinate resistance of upstanding rocks or banks that it wears them down,

or else heaps itself behind them and thrusts them out of its way.

The aspect of this placid but ponderous flow cannot be better grasped than in the comparison of a glacier to a roll of cloth, unrolled along a shop-counter; or better, Mr. Ruskin's example of the flow of stiff honey, or any tough viscous fluid. Not that ice is in other respects a viscous fluid; but its flow, taken as a whole, from whatever reasons in the nature of its own internal degelation and regelation, does behave rather as a viscous fluid behaves, than like any other substance. This is really the whole gist of Forbes's description of the nature of glaciers. While others analyze their details with very often false corollaries as to their proclivities and powers, Forbes grasped the function of ice-flows in their relation to physical geography. No one before him had understood the glacier to be anything but rigid: many after him have been led by the apparent rigidity of its fragments into the idea that it is a huge ploughshare, or chisel, or what not; and to the corollary that its action has been such as, in our Savoy, at any rate, we have seen is impossible. But Forbes stated the first, most general, most important truth about ice,—that in mass and in motion it has the aspect and attributes of a viscous fluid.

If you pile a heap of honey on a plate sprinkled with crumbs, the base remains where it was, in contact with the crumbs; the brow falls slowly forward, with greater haste in proportion to its height. The crumbs are gradually buried under the advancing tide, which *rolls* over them but does not remove them; for as each new crumb is covered the film of honey lies where it fell: and motion in the mass begins only above this lower film—always growing, but always stationary, being added to, but not moved. The edges move; the mass as a whole moves over the base-film; but that stirs never a crumb. This trifling tea-table experiment illustrates glacial motion in its general aspects. It will illustrate it still further if you throw dry crumbs on the top; which will now carry this surface-moraine along, while the bottom-moraine remains stationary. And when the surface-moraine reaches the edge it will be thrown overboard, forming a terminal or lateral moraine. For a viscous fluid advances not by sliding but by rolling. That is to say, the whole mass does not slide over its bed; though every particle in the mass does slide over the particle immediately below it. The difference is not one of degree merely. The process of sliding and regelation *in minimis* is a quite different thing from the disruption and

regelation of large masses; and is exactly Forbes's viscosity.

One might expect to find some outward and visible sign of this, if one could anywhere see a glacier in natural section. Such an opportunity is given in the Glacier des Bossons, over against the Pierre Pointue; where the ice, falling into a funnel-shaped chasm in the rocky bed, leaves a section clear. So far from any aspect of rigidity and angular fracture, all the contours and crevasses into which it breaks are curves, such as would be taken by a tough, viscous semi-fluid flowing over a steep and rugged bed.

In 1826, when the Glacier des Bois was invading the valley, it announced its approach by showers of stones from the top on to the châlets beneath; which is just what the honey does in its journey.

But if ice moves rigidly, thrust forward by pressure from behind, or sliding over its inclined bed, it will be illustrated by making a little glacier of scraps of sugar on a plate, loading with crumbs as before; and then pouring a few drops of water over it, which will melt it away, and let the surface-moraine sink down upon the ground. But that will not make a terminal moraine, which is always a distinct mound, the stones of which are thrown and piled at some little distance from the glacier,

as the viscous honey with its rolling flow will do, not as the rigid sliding sugar-heap.

The honey experiment illustrates also the flow of ice over a surface hardly, if at all, inclined. Even on a level surface it will extend itself; but slightly tilt the plate, and then even the bottom film will acquire a slight motion; but still very trifling in proportion to that of the top—a proportion regularly and constantly increasing from the bottom to the top, and from the middle to the sides. It is not mere friction which holds back the glacier at its sides; generally, the glacier touches its lateral moraine hardly at all. But such is the law of its flow—a law similar to that which rules the flow of viscous fluids in general; and the analogy from which glaciers have been likened to viscous fluids.

On a steep bed, then, and at the banks of its channel, the bottom moves; much more slowly than at any other part, but still moves; and to this slight motion is owing whatever little erosive action it exhibits. The projections are rounded off; rocks are scored and polished; but this is a widely different operation from the excavation of lake-basins. A glacier smooths a knob, but does not dig a hole. The glaciers are, both directly and indirectly, the great levellers. They carry the ruin of the mountains to fill up the ravines of the

valleys. They smooth or burst away projections to spread their detritus and fragments in the hollows; as the streams do, but much more slowly, and much more surely.

§ 3. THE MISSION OF GLACIERS.

After so much has been said upon what the glaciers did not and cannot do, a few words must be added upon what they did and can do. They did not excavate the lake-basins of Savoy: what was then their mission?

It was an important one, though not that usually assigned to them; and effected in four principal directions—in clearing or smoothing away obstructions; in filling up the valleys; in piling up moraines, which sometimes serve as dams to recent reservoirs, or as walls to recent valleys; and in keeping open the lakes.

The first department has already been noticed as a possibility. To this we owe much of the repose of the valleys, especially those great transverse "Cluses," in contrast with the ruggedness of the heights. The rounded woody knoll, and many a rolling moorland, with its soil rich for forest or pasture, are the results of glaciation. And conversely, for the boldness of the higher crags, from

which their *débris* has been carted by the ice-powers, they are equally to be thanked. But for the glaciers, the Aiguille Dru would be smothered to the waist in its own ruin; which now fertilizes the valley of the Arve, or banks its plains and bridges its buried chasms.

The old market town of La Roche in the Genevois is not set down as one of the sights of Savoy, though tourists must have often remarked its roofs and rocks on low hills to the right of Bonneville. But the absence of any grand Hôtel de Londres et de l'Univers tells that they hardly know what a quaint, old, interesting, up-and-down, hole-and-corner place it is, with its bit of ancient tower on an enormous limestone block, its ruined gate and gloomy remnants of a Burgundian palace, and its glorious view of the Alps and Mont Blanc. The houses stand demurely arow along the main street, and one would hardly suspect that their backs are all frilled and flounced with multitudinous little wooden galleries, crowded with flower-pots and clothes hung out to dry, high above the river. And the river, as if excited by such surroundings, foams and fusses down a sort of ravine sculptured in the best style possible to that material; really very torrential, with cascades in it, and into it. There is a good specimen of a "Devil's Bridge"

crossing the ravine (to which modern enterprise has added a Holborn viaduct and a railway bridge). But big rocks, stuck neatly into what you would not at first take to be rubbish-heaps, appear wherever there is a chance of producing effect. For all this is nothing but an attempt on the part of nature to make an artificial garden-rockery.

No real limestone strata rise to the surface for a great way round, and the nearest pretence of true rock is the Molasse, some little way to the south. All round La Roche the soil is just dirt and stones, loosely thrown down. But what stones! From Breson to Salève the ancient glacier of the Arve has built itself a great wall of boulder castles, upon a mound such as a dynasty of eastern kings in the dawn of history with their millions of captives might have purposed, but never could accomplish. And Mont Sion, which joins the Salève to the Vouache, is a still mightier monument of glacial power. All the materials of these mounds, and many such, were in the first place broken from higher crags, then too steep for equilibrium,—caught by the glacier and carried to where they are most useful. And from the time when this Savoy was fit for human habitation, the glaciers have dwelt there along with man, guarding him from those dangers which daily occurred of falling rock and

unsteady strata. As the mountains were gradually shaped into stability, and the need for the glaciers diminished, they have retreated; so that now none fear the crags of the Lanfon or the precipices of the Breson, but flocks feed up to their very foot; while in the still unsecured ranges of Mont Blanc the ice-fields still ward away all but the chamois and the tourists. And to-day, in the granite dust of deserted moraines, hardy flowers are blooming; little pines—things

> "To clasp into a giant's cap,
> Or fans to suit his lady's lap"—

are struggling between white boulders; and where last year's plants have died into soil of fertility, the fringe of waste wilderness is blossoming with roses. This is that wonderful natural providence, the economy of means to all manner of ends, which is so "necessary, and voluptuous, and right." But there is sadness in it too; for how we regret the glaciers, when they dwindle away, and the tourists reign in their stead!

Beside clearing away obstructions, levelling the valleys, banking them in and covering them with soil and substance useful to man, the glaciers have kept open, though not scooped out, the lakes. Those great moraines, which terminated the ancient *mers-de-glace*, are beyond and below the lakes. The

material of them—but that it has been carried over the basins on the backs of the glaciers—must have gone on accumulating, if carried down by water, until either it was spent or the basin filled up. So that so far as we have any old lake-basins left open at all, it is a result of glacial agency, acting in quite different conditions from those proposed by the excavation theory, or by M. de Mortillet.

Granting, as we may, the persistence of lakes—their previous existence to the glacial extension—what must have happened when the ice, gradually spreading down the valley, reached the water's brink?

This depends on two things—the thickness of the ice-stream, and the slope at which it flows. If you stand by a pond on a winter's day and push a lump of ice off the bank, it will float away over the water, a miniature iceberg. If you push out a good large flat piece until only one corner rests on the bank, whether under or above the surface, the rest will float none the less. But as it is bound to have many times as much of its mass under the water as it has out of the water, and as the stranded part is forced to be a good deal out of the water, the rest must be a good deal under water; the upper surface will dive, and the

ice will look as if it meant to sink. And of course if you press it down very hard with your foot you can push the block along the bottom, in spite of its buoyancy; but if you keep the pressure up only from behind, not vertically over all its extent, bits will break away, and come gurgling to the top; or if the pool be shallow, the ice-raft will strand.

That represents on a small scale what would happen if a glacier came violently down a steep place into the water, as it does on the coast of Greenland. Given a good weight of ice above and behind, the buoyancy of the icefoot is at first overcome; it is driven down to the bottom; the sea is too cold to melt it; buoyancy reasserts itself; great masses burst away, and rise to the top in huge roaring whirlpools. This is the case in Baffin's Bay, and at Cape Dudley Digges, as we are assured by Sir John Ross and Dr. Rinck.

But at the edge of your pond, where it is *not* steep, it would be quite possible to push off a sheet of ice, which should neither crack away nor sink to any appreciable extent; and indeed when the frost breaks up, it is common to see a table of ice big enough to walk on, all floating above the surface, and yet resting on a shelving water-edge.

And so, in Spitzbergen, at Fairhaven, is a glacier described by M. Ch. Martins, which sends out an

icefoot resting on the shore of the bay and floating freely in the middle. In the Aletsch glacier, too, and at the Ruitor lake, M. Agassiz has described how the unbroken ice creeps floating over the water, on a small scale. And in this case the comparative warmth of the water helps to melt and thin the ice underneath, so that it has still less chance than before of reaching the bottom.

Now when the old Rhone glacier swept down into the ancient lake of Geneva, it did not descend at any slope to speak of; and wherever and whenever the water was deeper than the ice, it floated; all the more so because the water melted away its under surface.* So that, when there was a great volume of water, the ice floated, and never touched the bottom at all.

Where the volume of water was small,—where the ice spread over the country like snow over a gutter in the street, or a folded table-napkin over a plate, the case was different. But then, even less than before, could the ice reach the basin-bottoms, except when its volume was greatly diminished,—and reduced, in proportion to the lakes, to the size when

* In the Q. J. G. S. for February, 1883, p. 81, Professor Blake says that "it was singular that, *as* the lake of Geneva had been filled with ice, Miocene fishes should still be found in it." But it is quite possible that there was plenty of water in the lake, under the ice, and that the fishes were never frozen up.

floating is possible. Under every glacier is a vault, of some dimensions and considerable length, often a perfect labyrinth of vaults, not filled with water, but kept open by water ; and always dripping with wet ; because a glacier is always trying its best to melt. The bottom of this vault, as we have already seen from Agassiz, is not bare scraped rock, but gravel ; through which runs the stream, doing its best to erode, and certainly rolling the pebbles ; which shows that the glacier does not weigh with enormous pressure all over the surface of its bed, and least of all at the lowest hollow of the trough ; a fact which by itself shows that the chief work a glacier does is not in cutting its bed deeper, since it weighs most heavily on the places that are not deepest. The dimensions of these vaults are in inverse proportion to the slope of the glacier, so that, when the bed is nearly level, the vault is very large.

Under the huge glacier which filled, for example, the valley of Annecy, in its level reaches, what a huge vault there must have been ! and all the more, because the weight of this mass was taken off the valley-bottom, and rested on the higher banks on either hand ; the ice-sheet covering the whole country being so enormously thick that the cohesion of the whole would make it swing across the basin,

and keep it from sinking as a dead weight into the hollow. In this hollow there must have been a river, big enough to drain the whole glacier, and that must have meant a considerable flow of water. And this water must have found a channel and an escape then as now; for a glacier even in the Pleistocene age must have been the same melting substance as it is to-day. This implies a great body of water to fill the vault, if not quite to fill the basin to its normal level; but at any rate, just where the excavation-theory postulates the greatest pressure or motion, or both, of the ice, there its motion was a minimum or zero, and its pressure zero; for there was the vault, and the river or sub-glacial lake.

In either case, therefore, when the basin was great or small, when the glacier was great or small, it is improbable, if not impossible, that the one ever touched the other. And the whole theory of glacial excavation is unfounded—as far as Savoy is concerned, seeing the valleys were all otherwise formed, and the glaciers all otherwise employed—the valleys all previously shaped by quiet, though mighty, physical forces; and the ice filling up, not digging out, hollows, and probably never touching the very troughs to create which it has been especially invoked by the popular modern theories.

But whatever were the detailed processes of their completion, in some such manner as this were the mountains of Savoy founded and fashioned, in remote revolving periods of oceanic influences, through æons of fire and eras of frost, through unimaginable cycles of universal turmoil and elemental travail.

And at last these Alps stood hewn into sufficient and stable completion, from fiery core to frosted crown, with every intermediate glory of fountain and foliage and flower; to which the Almighty Artificer is ever adding touch upon touch of still finer and finer, and yet never final finish. Might not so magnificent a monument of the labour of His hands suffice Him, that He should find content in it? Was He not now satisfied with the work of creation? Not yet: not while the temple so raised was still unbeheld by eyes that might be glad of its beauty; still untenanted by souls to comprehend its marvellousness, and hearts to uplift to its Maker the sacrifice of praise. Without man, the world was incomplete; and among the mountains also he was placed,—not, as elsewhere, congregated into companies of workers and worshippers, but here more completely in the Creator's image,—a sole inhabitant of sublimity; born to high thoughts, and bred to a lofty life, removed from the fever-fretted pettinesses of the inferior world.

And to all those whose good fortune leads them, though but for a little space, and in these latter days, to be guests in the homes of the hermits,—would they but open their hearts to the sanctifying serenity of a land so hallowed with histories of divine power and human piety,—to them also the wandering patriarch's angelic vision of grace would not fail to be manifested; from which awaking they might truly say, "This is none other but the house of God, this is the gate of heaven."

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